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Assessment and Planning Staff Report

Forum on Erosion Productivity Impact Estimators

James A. Maetzold
Klaus F. Alt

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ABSTRACT

In 1980, the USDA formed the National Soil Erosion - Soil Productivity Research Planning Committee to identify what information and research directions are needed to estimate the effects of soil erosion on soil productivity. A number of erosion estimators have been developed and field experiments have been undertaken since 1980 as a result of this effort. This forum reviews: criteria for modeling soil erosion-soil productivity relationships, accomplishments in modeling and other soil erosion estimators, comparisons of results, and identification of needed improvements. This report contains documentation of the accomplishments during the 1980 to 1985 period.

Keywords: Soil erosion, erosion-productivity, simulation model, field experiments

PREFACE

The U.S. Department of Agriculture's Agricultural Research Service, Economic Research Service and Soil Conservation Service made a concerted effort to develop and improve soil erosion-soil productivity estimators to measure the effects of erosion on cropland productivity. The erosion Productivity Impact Calculator (EPIC), the Productivity Index Model, improvements in the Universal Soil Loss Equation and other efforts have contributed to the development of scientifically based process models to depict the soil/crop/plant environment interrelationships.

The Forum on Erosion Productivity Impact Estimators provided the opportunity to present progress, discuss developments and identify uses and improvements. Past and present models were reviewed, status of present models was discussed, and future needs identified. The papers and discussions presented in these proceedings are grouped into four areas: criteria for modeling soil erosion-soil productivity relationships, accomplishments in modeling and soil erosion estimators, comparison of results, and identification of needed improvements. This report contains documentation of the accomplishments during the 1980 to 1985 period.

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INTRODUCTION: THE EPIC SYMPOSIUM

Estimating erosion rates and the impact of erosion on soil productivity have been major efforts in the U.S. agricultural research community for decades. Since 1980, the U.S. Department of Agriculture's Agricultural Research Service, Soil Conservation Service, and Economic Research Service have developed and applied the Erosion Productivity Impact Calculator (EPIC) to measure the effects of erosion on cropland productivity. Other models have been developed over the past decade to perform similar functions.

The Resources Conservation Act (RCA) Appraisal for 1980 focused attention on ways to better estimate the impact of erosion on soil productivity other than with statistical models. Attention has been devoted to develop scientifically based process models to depict the soil/crop/plant/environment interrelationships.

GOALS

This Forum on Erosion Productivity Impact Estimators was sponsored by the ARS, ERS, and SCS. The objective of this Forum was to provide an opportunity to present and discuss development and application of various national assessment modeling efforts, especially the RCA/EPIC model designed for the 1985 RCA appraisal.

The Forum was designed to focus on:

1. Role of soil erosion/soil productivity models.
2. EPIC model development and operation.
3. EPIC model assumptions, specfications, and limitations.
4. EPIS model assumptions, specifications, and limitations.
5. Results of the EPIC/EPIS process.
6. Results of other soil erosion/productivity impact estimators.
7. Use of results in policy development, program implementation and program evaluation.
8. Implications for further needs of erosion productivity impact estimator models.

HIGHLIGHTS OF FORUM

Several main points were raised and appeared to be generally supported by the attendees. These are highlighted to draw the reader's interest to the papers or discussion which provide the detailed arguments.

The points discussed at the Forum fell into four main categories:

1. Model Building and Validation. An overview of the process of model building and the approach to model validation were presented. The issue of validation was raised repeatedly; how can a model be validated when it simulates future events which may take decades to unfold? The models can serve as a learning tool to refine the professional expectations of researchers, but Forum participants identified the inherent problem that model predictions may not be accepted until model results reflect the prevailing wisdom. Thus, results of the EPIC model were repeatedly asserted to understate the future effects of erosion. On the other hand, the comparison of EPIC to the Productivity Index (PI) model showed little difference in the overall estimates.

2. Review of Past and Present Models. Three large-scale modeling efforts were reviewed: 1) the yield-soil loss model (Y/SL) used in the 1980 RCA analyses, developed by Paul Dyke and Linda Hagen, 2) the PI model developed by Bill Larson, Fran Pierce, Bob Dowdy, and other soil scientists based on modeling developments in the late 1970's and early 1980's, and 3) the EPIC model developed by scientists from ARS, SCS, and ERS over the last several years and used in the 1985 RCA appraisal.

3. Status of Present Models. The Y/SL model has not been used since the 1980 RCA analyses; there is no expectation that it will be used for further work. The PI model has been applied successfully to soils in the Corn Belt, and will be used in other regions when the model has been modified for those regions. The EPIC model has been run for 12,000 soil/rotation/tillage/conservation-method combination for the 48 contiguous states, and the EPIC interpolation routine has extended these results to many other soils and resource situations. The EPIC/EPIS data results presented here are documented and extensively analyzed in a series of Economic Research Service reports.

The results of the three models predict that the erosion-induced productivity losses will be relatively minor (less than five percent) by 2080 for most soils, but more than 20 percent for a few soils.

All three models help identify the particularly vulnerable soils, and this identification can aid in directing resource conservation activities. During the forum, the argument was made repeatedly that it would be misleading to look only at the average productivity loss (say 2 percent over 50 years) and on that basis to dismiss erosion as a problem not worthy of research expenditures. Average figures conceal that specific soils may have a significant productivity loss if erosion is not controlled.

4. Future Needs. The participants agreed that further research on models like EPIC or PI would lead to improved certainty of where to apply erosion-reducing activities--in specific geographic soils, specific tillages, or some other identifiable category. Participants made numerous suggestions of what to improve in future editions of the EPIC or PI models. Most of these suggestions were related to perceived limitations of the present model specifications and fell into broad categories: micro and macro. The micro-level limitations include such questions as whether the soil-internal processes are simulated properly, such as the erosion-induced changes in the soil's fertility (and its replaceability by increased fertilization), changes in seed germination and root growth processes, or other effects of erosion on any limiting factor for plant growth. The macro-level limitations stem from the present model's point-specific nature. Participants argued repeatedly that erosion (and its effect on soil productivity) should be considered on a whole field or hillside basis. The position of the eroding point in the landscape and its slope (concave or convex) influence overall productivity in ways that the present models do not capture. The macro-level limitations also may be extended to include the effects of ephemeral erosion and gullying; the overall change in productivity from these sources is not included in existing models. Finally, the models are limited to onsite effects, but the offsite effects of erosion and sedimentation exceed the onsite effects in magnitude.

SUMMARY

This report documents the papers and the discussion at the May 8 and 9, 1985 sessions. Even though this is not a verbatim transcript, the editing has been minimal to allow the reader to follow the flow of the discussion.

PURPOSE OF MEETING

By Klaus Alt

This forum is sponsored by the three agencies directly involved in the development and use of EPIC--Soil Conservation Service, Agricultural Research Service, and Economic Research Service.

The purposes of this forum are to review the EPIC model and its development process; to present the RCA EPIC model specifications, assumptions and limitations; to present the RCA input and output data; to compare those data against other model outputs as well as inventory data such as the NRI; and to address new model development and databank modification needs. The forum breaks into three parts: (1) how the EPIC, PI, and other models were developed, how they were validated, how they work, (2) what numbers have been estimated by use of the EPIC model for the RCA process, and (3) what additional questions and additional research on erosion productivity impacts could or should be undertaken.

One thing you do not see on the agenda is that this meeting will be followed directly by a three-agency planning meeting within USDA to identify a joint plan of work for the next several years on EPIC and EPIC soil erosion/soil productivity (SE/SP) related activities. We specifically wanted to have the output of this forum lead into that discussion on the EPIC plan of work and more overall SE/SP research and application.

The development of the numbers from EPIC for the '85 RCA process has effectively reached a plateau. The EPIC group has finished what numbers it could contribute to the RCA analysis. We had a discussion in February with the RCA concern leaders to identify at least in summary form how those numbers were derived. What we would like to do here is to be a bit more detailed about what was done, how those numbers were derived, and what they mean. It strikes me as a responsibility of all of us research managers at this point to engage in an evaluation of the completed project to see how well what we have done fits what the demands were, both for information for the CARD model, per se, and for the RCA process in general.

AGENCY KEYNOTE COMMENTS

By Ronald Follett, Agricultural Research Service

It is important to look at a number of erosion and soil productivity related activities in a broader context first before we get down to the specifics of this forum on erosion productivity estimators. There's no question that the impacts of erosion on soil productivity were recognized for many, many years. Back in the 1930's and through about 1950 there were many studies completed nationally. This early research involved various experiments on soils, fertilizers, and so forth. The passage of the Resource Conservation Act of 1977, with its specific mandate to USDA to assess the condition of soil and water resources of the United States every five years has really pushed those of us interested in soil conservation to take another good hard look at the impacts of erosion. Tools that weren't available back when some of the earlier work was done can now be used to see if we can advance this science.

When we started into the 1980 RCA appraisal, we used a yield/soil loss relationship based on statistical data. This first attempt to develop nationally applicable mathematical models sparked great interest in the crop yield/soil loss relationship, and a workshop of federal agencies was held in Washington, D.C., in February 1980. There's quite a number of you here today who were at that first meeting and who have been involved in the entire process. One of USDA's first efforts was to form the National Soil Loss/Soil Productivity Research Planning Committee which reported on the status of the knowledge at that time. We then went ahead at USDA and held a planning meeting in Lafayette, Indiana, in September 1981. Those who attended identified four thrusts, and this is where I want to bring this total context together. They wanted to look at the mechanics of wind and water erosion. They wanted to look at erosion/productivity experimentation. They wanted to look at the modeling aspects, and they recommended a thrust on conservation tillage.

All four of the above mentioned thrusts are continuing, and that's really the point I want to make.

In mid-April at Lafayette, Indiana, there was a meeting on the erosion mechanics thrust.

Well, this could be a follow-up on the thrust on wind and water erosion modeling mechanics. Attendees at that meeting were dealing primarily with improvement and replacement of the USLE. My understanding is that on May 14 in Kansas City, there will also be a workshop on the wind erosion equation. Many of you are familiar with some of the efforts on conservation tillage. There was a national meeting in Tennessee last year. There was also a meeting on soil microbiological relationships in conservation tillage systems in Seattle last year. Regarding the experimentation part, there probably does need to be a follow-up on some of the experimental approaches. There are, however, active groups. There's a Southern Regional Committee, there's a North Central Regional Committee, and, of course, ARS has a very active program. The meeting we are having today is a follow-up on some of the modeling efforts that USDA has. So it's all fitting together and I'm pleased to be here to help represent ARS.

AGENCY KEYNOTE COMMENTS

By Ralph McCracken, Soil Conservation Service

We appreciate this opportunity to make some keynote remarks. I'm taking as my mission to lay out what some of the overall concerns and interests of SCS are. Let's first talk about the genesis and impetus for erosion productivity impact estimators within SCS. It was the 1980 RCA appraisal process that gave the genesis and impetus within SCS at least. So, now we see a whole series of opportunities and needs and uses for erosion productivity impact estimators. I will address EPIC for the rest of my comments here, including use of it for the 1985 RCA appraisal process, which is now strongly underway; for policy analyses of various sorts; for program evaluations, including those that were mandated by the RCA legislation; for program administration, including not only administrative management, but also allocation of funds according to targeting or other indicated program needs as a result of feedback from the models of various sorts; for regional and state watershed plans; and for technical assistance at the field level. We very much need to keep in mind that with SCS moving swiftly towards providing microcomputers in each and every field office (which we expect will be accomplished within two to three years if all goes well) there will then be a great deal of importance and value for some version of EPIC downsized for the field office level. So we have this whole array of uses, needs, and opportunities within SCS for EPIC, whatever form it might take, whether it be a supermodel or sets of models, or supermodels downloaded and downsized as appropriate.

What are some SCS interests and concerns, given those needs and opportunities for uses within the service? There's one category which I've described here as validation, sensitivity, statistical reliability, and working together for avoidance of misuse and misrepresentation of model outputs, whatever models they might be. I think that's particularly important because of the high visibility that model outputs are getting and will increasingly get in the future. I think it behooves all of us to take special steps to describe the assumptions, qualifications and statistical reliability of the various model inputs. Documentation will be very important, from the standpoint of soils data, soils descriptions and other model components and data bases. Priorities will be addressed by my colleagues from SCS later, so I won't dwell on this, but a few items are--areal versus point approaches, sharpening up the weather aspects, soil properties (including some that have not been fully considered), cropping systems, wind erosion, offsite effects, and so forth.

A point that gets more on the administration or mechanical side concerns what the tri-agency group needs to discuss. That is the relative roles and responsibilities, or to put it another way, the need for role definition and responsibility. Is the model to be a turnkey system, a push-button system that would be presented to SCS by a research agency, or do we work together and meet at some point? How far does technology transfer go with respect to the primary, research agencies such as ARS and ERS with respect to hand-off to SCS? So

this matter of the the model transfer and the relative role and responsibility for the agencies needs careful and complete discussion as we move ahead.

A personal concern of mine, and I'm sure of others, is a better understanding of population models, in this case the soils, spatial variability, erosion over a field, or the variability in yields, topographic position and location somewhat independent of the degree of erosion. I think we must give a great deal more attention to description and recognition of the properties and the spatial variability of the particular populations that are being modeled or simulated.

With respect to some SCS commitments, there has been agreement within the SCS administration to participate in a five-year plan with specified maximum funding levels. Also, there's been a commitment that SCS will supply at least two full-time professionals at Temple, Texas, if that activity is indeed to continue there, including the specialties of soil science and analysis and economics. SCS has agreed to and is quite willing to support and participate in such quarterly or such periodic reviews and validations of various types of model development, EPIC and others. The level of commitment for each of these activities is contingent, of course, upon funding availability. We want to stipulate a continuing interagency cooperation and indicate the need for advisory or technical committees. If this process is to continue, we need to move a little beyond the current informal setti gs.

In summary, wide ranges and levels of uses for EPIC exist in SCS. There are concerns for validation, documentation, representation, appropriate uses, priority, agency role and responsibility, and definitions. Pledge of continuing SCS support and interest is contingent, of course, upon funds, interagency negotiations, and agreements. We recommend highly the formation of two committees--an advisory or steering committee and a technical committee. I want to close with this reminder that we expect very shortly a detailed report and set of recommendations from the National Academy of Sciences National Research Council with respect to the convocations and workshops that were recently held, and we think those will be particularly significant.

AGENCY KEYNOTE COMMENTS

By Tony Grano, Economic Research Service

Klaus mentioned three objectives for the conference. One was to examine the development, validation and the mechanics of EPIC. The second one was a review of the results and a comparison to the results of other models. The last objective was to identify where we go in the future with EPIC. It is concerning this last objective that I want to lay out two or three ideas. ARS, SCS, and ERS will be examining where we go with EPIC over the next few years. This meeting provides a forum for the discussion of where we have been, what went right and wrong, and what are the possible future directions for EPIC. It is this, the identification of the future directions for EPIC, that will be crucial to us.

I think one of the areas that we need to look at very carefully is the improvement of the current modeling efforts and the data base. How can we make EPIC more useful than it currently is and what other applications would make it more useful to more people? Secondly, how do we improve our capability to address high priority research needs with EPIC? SCS, ERS, and ARS, on a yearly basis, identify high priority research needs that they see coming up in the future. The recent non-point pollution conference is a good example of one possible application of using EPIC in the future identification of offsite impacts of erosion and sedimentation. Can it provide some useful input to that research process? Third, I'd like to see that EPIC provides timely and relevant inputs to policy issues and analysis. Numerous questions are being raised by people about where we get our greatest returns for our conservation dollars spent. I think EPIC can aid us in that exercise, when combined with other procedures, data, and models. Fourth, how do we improve the efficiency of existing programs and provide some guidance to their redirection. I visualize EPIC as being a useful tool to address issues related to conservation programs, targeting, and so forth. Lastly, how do we use EPIC to aid in the development and design of new programs and mechanisms for their implementation? I think the information that EPIC develops and its linkages with the CARD model and

with other economic components for the 1985 RCA appraisal will provide some of this information. And then I think one of the things that we need to think about regarding EPIC is what is its potential role in international programs. That is an issue that the agencies are addressing.

We are looking for the advice and counsel of the researchers, the program managers, and the users of EPIC inputs and outputs to provide some guidance for us in the decisions we are going to make over the next several days about where we go with EPIC. Hopefully, this forum will achieve those kind of results.

THE EFFECT OF EROSION ON PRODUCTIVITY: ROLE OF MATHEMATICAL MODELS

By Kenneth Renard and Donald Meyer

Introduction

The advances in digital computer modeling have closely paralleled the development of computers in general. As computers have decreased in price and physical size, yet increased in problem solving capacity and speed, our ability as scientists and engineers to emulate prototype systems has progressed until we can often postulate models that are more complex than our ability to make prototype measurements with which to validate the model components. Simultaneous with developments in computer software and hardware have been developments of graphic capability which help facilitate interpretation of computer simulation, both in space and time.

The United States Congress recognized the potential of models in the successful planning and management of water resources. Congress instructed the Office of Technology Assessment (OTA) to (1) assess the nation's ability to use models efficiently and effectively in analyzing and solving water resource problems and (2) make recommendations for improving the use of available technologies.

The OTA Report (1982) had some interesting comments about mathematical models. The following quote pertinent to model development is from the OTA Report: "Mathematical models are among the most sophisticated tools available for analyzing water resource issues. They can use the capabilities of today's digital computers to perform and integrate millions of calculations within seconds in order to understand and project the consequences of alternative management, planning, or policy-level activities. Models not only assist in decisionmaking--they provide information that people must interpret in light of existing laws, political and institutional structures, and informed professional and scientific judgment. Nonetheless, models can significantly improve the informational background on which decisions are based, and substantially reduce the cost of managing water resources."

The objectives of this paper are:

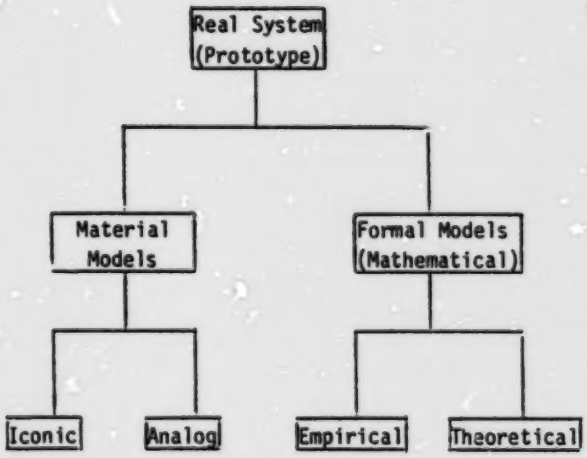
1. To introduce the concept of modeling for predicting the effect of erosion on soil productivity,
2. To illustrate how conceptualization in a model can lead to parameter distortion,
3. To illustrate the importance of model flexibility for problem solving,
4. To describe the processes of developing an operational model,
5. To describe some limitations for model use, and
6. To project some future trends in natural resource models.

Modeling Semantics

Much material has appeared in recent years regarding model classification. In an excellent introduction to the subject, Woolhiser and Brakensiek (1982) point out that although criteria used in model classification vary (the criteria vary with special interests or the needs of a particular discipline), models can generally be classified as either "formal" or "material" as suggested 40 years

ago by Rosenblueth and Wiener (1945). A formal (intellectual) model is a symbolic, usually mathematical, representation of an idealized situation that has an important structural property of the real system. This is the most common model type used in natural resource problem solving. A material model is a physical representation of a complex system by a system having a simpler structure than the real system, yet preserving the most important properties of the prototype. The iconic model (a look-alike) is a simplified version of a prototype system which uses the same materials as a prototype (e.g., a hydraulic model uses a fluid although not necessarily the same as the prototype fluid). Rainfall simulators, lysimeters, and experimental watersheds are other examples of iconic models. In an analog model, the model quantities measured are of a different substance than in the real system. One of the most common analog models is one which measures the flow of electric current to represent the flow of water. Material models were dominant in water resource problem solving up to a decade or so ago, but they have been largely replaced by mathematical models. However, the results of experiments with rainfall simulators, lysimeters, plots and experimental watersheds provide most of the validation tests for mathematical models.

Figure 1.--Model classification (Woolhiser and Brakensiek, 1982).



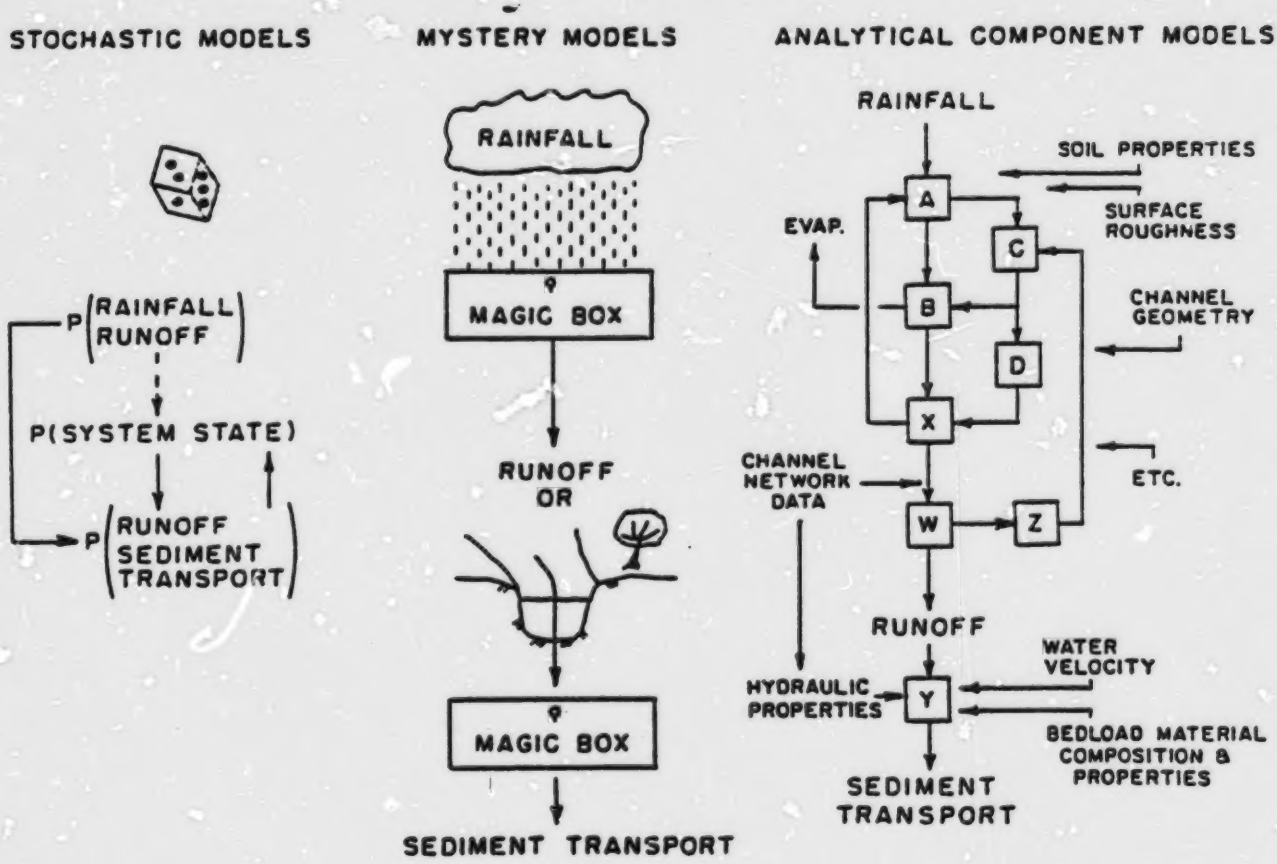
A theoretical model includes both a set of general laws, or theoretical principles, and a set of statements of empirical circumstances. On the other hand, an empirical model omits general laws (e.g., law of physics), and is, rather, a representation of real-life data (the Universal Soil Loss Equation (USLE) being a well known example). Thus, in an empirical model such as a regression relationship, two variables may appear to be physically related (and thus a theoretical model) when, in fact, they are not. A schematic diagram of this model classification is shown in Figure 1.

On a more practical sense, the techniques used in mathematical modeling involve a conceptualization as illustrated in Figure 2. In a stochastic model, the probabilistic nature of the system is preserved, with occurrences often having a time- or space-dependent structure; whereas a purely probabilistic system is time- and space- independent. Thus, in a stochastic model, the structure and the distribution characteristics of variates are determined from sample data (sample functions) and Monte Carlo techniques are often used to produce synthetic sequences of the variates because analytic results often cannot be obtained for realistic models.

Mystery (also called "magic" or "black box") models utilize a given input which, when converted by a mathematical transformation or function (they may have physical significance), produces the output. Such approaches have been widely used by hydrologists to convert rainfall excess to a runoff hydrograph by a unit hydrograph technique.

Finally, the analytical component model uses the physics of a process(es) to produce the required output. Although this type of modeling approach may be the most expensive of the three approaches (because it requires more algorithms, increased computer time, and extra field data), it should provide the most reliable results (assuming parameter values are known), especially when management alternatives are to be evaluated. This modeling approach is used extensively throughout the EPIC model (Williams et al., 1983), although the climate routine of the model uses stochastic principles. Such component models are often termed causal models in the literature.

Figure 2. Commonly used approaches for mathematical modeling of sediment transport.



De Coursey (1983) points out that dynamic "causal" descriptions of the subprocesses involved in a particular problem solution aid in

> "(1) structuring the data collection program, (2) studying the response of a research site, (3) selecting and evaluating parameters, (4) determining the accuracy used in evaluating input variables and parameters through sensitivity analyses, (5) studying the significance of spatial and temporal variability of physical features such as infiltration, and (6) determining how many observations are needed to achieve a given degree of accuracy in a specified period of time."

Why Model The Effect of Soil Erosion on Soil Productivity?

Many complex cause-effect relationships are involved in the way soil erosion affects soil productivity. For example, the fact that erosion reduces the soil depth and thereby the moisture reservoir for plant growth is well accepted. We also know that erosion changes soil surface characteristics which may affect infiltration. Erosion also changes soil physical and chemical properties which, in turn, affect the potential of the pedon to produce a crop. Given these interrelationships, plus the climatic variations across the United States, the thousands of different soils involved,

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and the different tillage and cropping systems, the net result is a maze of combinations that are difficult to "put together" in an objective way. By using a computer simulation model we have a feasible means to facilitate the many computations required to achieve the mandates of PL 95-192, the RCA legislation.

Many years ago in their discussion of the role of models in science, Rosenblueth and Wiener (1945) stated:

"No substantial part of the universe is so simple that it can be grasped and controlled without abstraction. Abstraction consists in replacing the part of the universe under consideration by a model of similar but simpler structure. Models . . . are a central necessity of the scientific procedure."

Chris Johannsen (1983), past president of the Soil Conservation Society of America, stated, "The failure to consider seriously the use of computers in your work could make the difference in future advancement." Testimonials such as these are common occurrences in natural resource scientific literature.

The OTA report on Water Resource Models (1982) points out that:

> "Mathematical models have significantly expanded the Nation's ability to understand and manage its water resources. They are currently used to investigate virtually every type of water resource problem; for small- and large-scale studies and projects; and at all levels of decisionmaking. In some cases, models have increased the accuracy of estimates of future events to a level far beyond 'best judgment' decisions. In other areas, they have made possible analyses that could not be performed empirically, with or without computer assistance. Further, models have made it feasible to quantitatively compare the likely effects of alternative resource decisions.
>
> Models are often the best available alternative for analyzing complex resource problems. While many of the economic and social factors in water resource decisions cannot be fully enumerated, models can be used to integrate the available data, and provide estimates of future effects and activities. Such estimates are highly useful in evaluating the consequences of different resource policy options, and are often less expensive than conducting comprehensive surveys and using other traditional approaches.
>
> Models have the potential to provide even greater benefits for water resource decisionmaking in the future. As models are refined and receive wider acceptance, they will be able to increase the efficiency of water resource management and encourage cost effective decisionmaking. Such models can do much to increase the rationality of regulations and the standard-setting process, and can generally provide a sound scientific basis for water policy."

To address the question of the impacts of soil erosion on agricultural productivity, it was necessary to develop a model incorporating many of these features. The resulting model (and the computer simulation program implementing the model) is called EPIC for Erosion Productivity Impact Calculator. As the EPIC model was conceptualized, programmed, and evaluated, the following important criteria were considered:

Availability of data

Degree of accuracy required

Computational time necessary

Balanced approach to the entire system.

Such items are a part of the model building not only for EPIC and PI (Larson, et al., 1974), but for modeling in general. Since we feel sure that others that follow on the program will elaborate on this topic, we will proceed to other items regarding model development.

Models must be capable of considering several "shocking" facts in an orderly manner, and EPIC is no exception. For example, an annual rainfall of 30 inches over an area of 1 mi^2 amounts to several quadrillion (? x 10^{15}) drops with a volume of more than 500 million gallons. These

drops have an impact energy (kinetic energy) of 30 billion foot-pounds, an amount equal to the energy of 10,000 tons of TNT. Thus, a soil erosion-productivity model must consider the temporal and spatial variability of precipitation, plus maintain a mass balance for both the water and the energy involved. Further problems that the model must accommodate are illustrated with respect to specific characteristics of the rainfall and runoff in Table 1.

Table 1.--Differences between erosive rainfall and runoff which must be reflected in a physically-based erosion-productivity model.

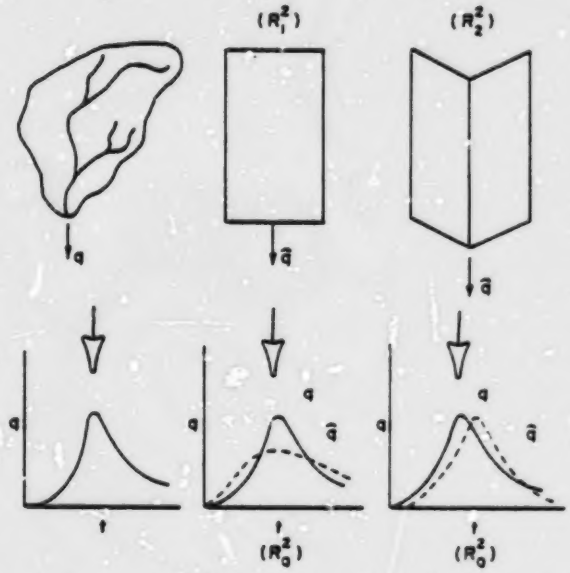
Characteristics	Rainfall	Runoff
Direction	Downward	Near horizontal
Area affected	Entire area	Small part
Erosive potential	All	Only part
Velocity	Up to 30 ft	Less than 3 ft/s
Form	As drops	Accumulations

Conceptualization of the Effect of Erosion on Productivity: Parameter Distortion

Whereas erosive rainfall occurs over an entire area, runoff affects only a portion of the area. Numerous other aspects are important for developing a model that is capable of emulating the soil erosion-productivity problem, including nutrient cycling, disturbance to the soil from tillage/harvest operations, plant growth problems, etc. The EPIC model accommodates these interrelated processes with algorithms, many of which have feedback mechanisms such that alterations in some segment (or model subroutine) have a cascading effect on other components. Although the human mind can comprehend how all these actions and interactions occur, formulation in a computer model greatly facilitates the quantitative description of these interactions.

The soil block (pedon) shown in Figure 3 is the computational element used in the EPIC model.

Figure 3.--Computational model of soil block (pedon) used in EPIC.



Although this model considers the layers of soil contained in such a block, it does not consider the micro changes that occur in such a system due to the creation of macro-channels from rodents, root decay, etc., nor the consolidation of the surface soil following tillage and the associated disappearance of such macropores. Thus, in some respects, the model allows spatial variability, and in other cases does not.

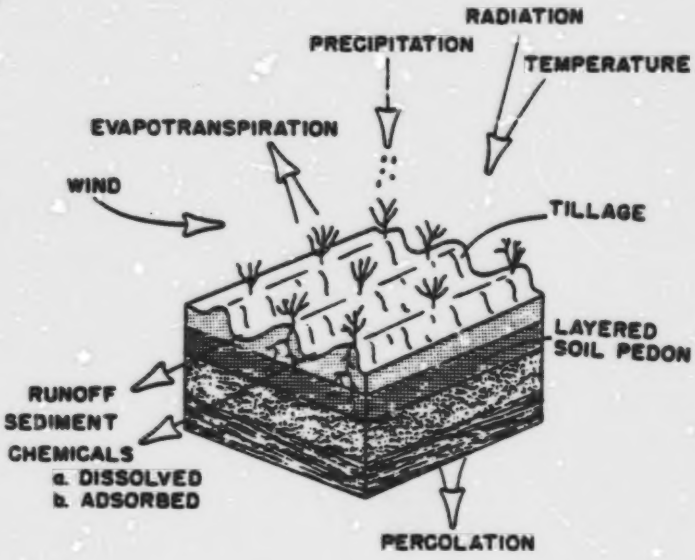
Such problems have long perplexed modelers; the problem has been addressed in hydrologic literature at various times. Lane and Woolhiser (1977) used kinematic flow equations to illustrate how runoff from a natural watershed shown schematically in the upper left portion of Figure 4 produces the observed hydrograph, q, in the lower left portion of the figure. A single plane (upper center portion of Figure 4), fit to the topographic data (x, y, z coordinates) and producing R_1^2 as a geometric goodness-of-fit statistic, then yielded the hydrograph labeled q in the lower center graph. From the observed (q) and fitted (q) hydrographs, a

goodness-of-fit statistic, R_0^2, was obtained. The same procedure was completed for a Woodling configuration (open book on the upper right portion of Figure 4) which produced further goodness-of-fit statistics. The computer program used in this effort produces optimal hydraulic roughness values for the planes and channels, separately.

The point to be made is that by increasing the number of planes and channels, and thereby increasing the geometric goodness-of-fit (model to prototype) and the resulting geometric goodness-of-fit statistic, the parameter values become less distorted. Optimal roughness parameter estimates will likely increase as the geometric distortion in simplified models decreases. More realistically, parameter values from similar experiments may differ because of different distortions imposed in the model emulation of the prototype. For example, a common problem in hydrologic modeling involves use of the Manning equation for channel flow. The roughness term "n" used in this algorithm often differs from textbook or handbook values. In a simulation model, the straight channel approximation of a real channel (Figure 4) results in using an artificial roughness value in the model that is actually a fitting, optimization, or tuning coefficient.

Problems such as these are common to all models--EPIC and PI being no exceptions. The real problem is in defining how limiting these assumptions are to the objectives of the project for which the model was designed to provide guidance. In the EPIC model, topographic approximation is used to represent a "typical" pedon and slope in a Land Resource Area. Furthermore, a generic soil description is used, along with typical agronomic practices (planting, tillage, harvesting, etc.), and a stochastic climate sequence for a specific year. That these conditions may or may not represent what might be measured for a specific prototype condition must be recognized. If, on the other hand, the results are used to compare crop yields from alternative management practices, the resulting data, expressed as differences or ratios, may be very realistic.

Figure 4.--Schematic representation of a watershed, simplified models, and associated goodness-of-fit statistics (Lane and Woolhiser, 1977).



Model Flexibility

It is probably not necessary to enumerate how models can be used to assist with decision making. We assume that most of you have experience with modeling in some way or form. What is important to realize is that modeling (and especially modeling of complex systems) may be revolutionary in its original conceptualization, but it is generally followed by an evolutionary process where it undergoes refinement and fine tuning.

A model is a formalized presentation (in a mathematical sense) of what our mind perceives or expects might happen for a given set of external perturbations. The advantage of the mathematical representation is that such an explanation should be understood the same way by everyone. If other reviewers do not agree that this is the way things would likely happen (based on their experimental data or experience), they can suggest an alternative for one or more algorithms of the model, and

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further hypothesis testing can proceed; thus, the idea of model evolution. Furthermore, new subroutines can be added or substituted as more new knowledge becomes available, or as the objectives for the model change.

Flexibility has been an essential consideration in the development of the EPIC model. Although the basic concept of considering such major components as climate, hydrology, erosion, plant growth, tillage, etc., has been preserved since the first meeting of the modeling group at Mississippi State University in May 1981, numerous changes have been made in the subroutines. The result is that we are to hear a description of the EPIC model in the forum that may well be the 25th version. Without question the simulated answers of how erosion affects productivity will also have changed markedly, although not in every situation.

A final aspect of flexibility in a model like EPIC concerns the ability of such a model to represent what happens over a wide variety of climatic, physiographic, and agronomic conditions. As a requirement for the RCA process (PL 95-192), it was necessary to quantify how erosion affected productivity in not only the many cultivated cropping systems encountered in U.S. agriculture, but also on rangeland, irrigated cropland, and for 11 major crops on several thousand different soils. Thus, the model had to have the flexibility to work with such heterogeneous conditions.

Development of an Operational Model

The utility of any model depends upon

Ease of use,

Completeness of validation, and

Accuracy of prediction.

The ease with which a model can be operated obviously has much to do with its acceptance in the user community. In the vernacular of the computer community we must develop "user-friendly" computer programs. However, the problem often goes beyond the actual computer mechanics, and includes the need for direct prototype measurements which then become inputs to the computer model. If such measurements are extensive, they greatly increase the cost of model simulation. In the case of the EPIC model and its input for the RCA process, computer files were developed for the climate generator, soils data, and machinery operations, with the net result that the operation was streamlined immensely. In other instances, where parameter estimates were required but not widely available, the parameter was generated by other means, or a default value was used (with some sacrifice in accuracy).

Model validation is essential to any modeling effort. Unfortunately for the EPIC effort, data are essentially nonexistent for testing the model in its entirety. Furthermore, a model of this complexity is not directly amenable to experimental test. Thus, model validation consisted of (a) detailed testing of model components (subroutines) with observed data from a wide variety of experiments in some instances (e.g., the climate generator), (b) using widely accepted pieces of technology in other instances (e.g., the curve number and USLE submodels), and (c) more limited testing in other instances (e.g., some of the nutrient routines and Ritchie's evapotranspiration algorithm). To evaluate this model as a package, simulations were completed for a wide variety of locations, cropping systems, and management systems to observe whether the input and output data resembled what scientists expected in the region. Furthermore, tests were performed to see whether the model preserved the statistical properties of agricultural conditions for a region. This work led to numerous adjustments of model parameter values, and indicated some conditions for which the model needed modification. The simulation was repeated to observe if the new simulation was close to values expected in a region. Such user feedback is essential to the development, testing, validation, and acceptance of such technology and its importance cannot be overemphasized.

In this effort, as has been observed in other modeling development, our ability to conceptualize and model prototype conditions has progressed more rapidly than our ability to collect the <u>in situ</u> data for verification.

When Are Models Limiting?

The limitation for the use of models is closely related to the type of model being developed. For example, some models are intended to be site specific (e.g., most iconic and analog models, in other words, material models in Figure 1), whereas other models are intended to be of a general nature (e.g., the mathematical models in Figure 1). For mathematical models of an empirical nature, care must be exercised when extrapolating the results beyond the conditions for which the data was available to develop the model. An example of such an extrapolation is the extension of the USLE to rangeland and forested conditions with minimal pertinent data for parameter validation.

With theoretical mathematical models, the intent is to conceptualize a model and define the parameter values for a variety of conditions such that the model can be used without calibration. The intent with some of the recent Natural Resource Models developed in ARS was for this condition. Models like CREAMS (Knisel, 1980), EPIC, SPUR (Wight, 1983), and SPAW (Saxton et al., 1974) are intended for use without calibration, although the availability of data to test the simulation greatly improves the confidence of the user. Even with these theoretical models, care must be used when applying the model outside the context in which it was developed.

Finally, one other problem that is evolving with many natural resource models (we use this limitation because of our familiarity with them) involves the need for elaborate and detailed training as a basis for use of such models. Some of these models have become so complicated that it requires a highly trained scientist or engineer to use the technology. Some model developers seem to assume the work is done when the model is published in scientific literature, and are not willing to take the needed extra step to ensure development of user manuals, user-friendly pro- grams, etc.--the need for technology transfer.

Future Modeling Efforts

Future modeling trends are somewhat difficult to project, except for very short time frames, because of the dynamic nature of the computer hardware and software industry. Having received much of our formal training during the times of slide rules and electro-mechanical calculators, advances within the last three decades are astonishing. Computer storage that once occupied large rooms can now be contained on a single chip, so more miniaturization that can make a significant difference hardly seems possible, either in cost or weight. However, three things likely will occur in future models for agricultural applications.

1. Some farmers and other business people as well will use models in their daily operations.

2. There will be considerable effort to download large programs from mainframe computers to mini, or even personal computers, and many of these will operate in the field on portable computer units.

3. Artificial intelligence (AI) and a subset of it known as expert systems will play an increasingly important role.

These projections may seem conservative to many of you because we can already do many of these things, although the costs may not make all of them economical in 1985.

Artificial intelligence research has several goals, including the development of computational models of intelligent behavior, both its cognitive and perceptual aspects (Duda and Shortliffe, 1983). A more engineering-oriented goal of AI is the development of computer programs that can solve problems normally thought to require human intelligence. The field of AI consists of several areas, including speech recognition, language understanding, image analysis, robotics, and consultation or expert systems. This latter area is the one with the most immediate application in agricultural research (Michie, 1983) and, specifically, natural resource problem solving.

The goal of expert systems research is to provide tools that exploit new ways to encode and use knowledge to solve problems--not to duplicate intelligent human behavior in all aspects. The simplest, and generally the most successful, expert

systems are classification programs. Their purpose is to weigh and balance evidence for a given case to decide how it should be categorized.

The identification and encoding of knowledge is one of the most complex and arduous tasks encountered in the development of an expert system. And in fact, the very attempt to construct a knowledge base often reveals knowledge gaps in the subject, as well as weaknesses in available representation techniques. A major effort in the development of the expert systems, then, is to overcome these gaps and to build a system where future knowledge can readily be introduced.

In summary, an expert system is one in which a nonexpert uses a computer program to help arrive at the same decision an expert would. An expert system is a way to "take advantage" of an expert's knowledge in some subject area and convert it, via a computer program, to assist in problem solving.

Summary

Erosion-productivity models have already had a significant impact on the RCA process (PL 95-192) in USDA. It seems likely that their role in the 1985 assessment will be even more dramatic; at least the results of the model simulation promise to be better than those of the 1980 effort.

The fact that models play an important role in RCA is not serendipitous; rather, it is a credit to those in RCA leadership who recognized the power of models to assist with problem assessment, problem analysis, and the consequent judicious management of our nation's soil and water resources.

We have introduced the subject of mathematical models, identified schemes for their classification, discussed problems encountered when using models, identified some modeling limitations, and finally made some projections regarding what we expect models to do in the future. The "sky seems to be the limit" in models, only restricted by our ability to collect prototype data to validate the built-in assumptions that limit such models.

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DESIGN, OPERATION, AND HISTORY OF EPIC

By Jimmy Williams

The Erosion Productivity Impact Calculator (EPIC) model was designed to determine the relationship between erosion and productivity. The EPIC model started with a meeting of several USDA agencies here in February 1980. At that meeting the National Soil Erosion Productivity Research Planning Committee was appointed. They developed the state-of-the-art paper "Soil Erosion Effects on Soil Productivity", a research perspective that was published in the Journal of Soil and Water Conservation. The third major step came in the development phase at a meeting in September 1981 at Purdue. At this meeting, four thrust areas were formed--modeling, field experimentation, erosion mechanics, and conservation tillage. My remarks today will be limited to the modeling effort.

The modeling group was formed with a team of 14 researchers from three agencies and several locations throughout the country. The model was first reported operational in May of 1982 at an international symposium on ecological modeling at Fort Collins, Colorado. The latest major development to report is the completion of 15 to 20,000 runs for the 1985 RCA in December 1984.

In developing the EPIC model, the major objective was to develop a mathematical model for use in determining the relationship between erosion and productivity. To do that we felt the model needed to simulate the physical processes involved simultaneously and realistically using readily available inputs. The model also had to be capable of simulating hundreds of years because erosion can be a relatively slow process. We wanted the model to be generally applicable, computationally efficient, capable of computing effects of management changes, and operational by July 1, 1983, to provide information for the 1985 RCA.

Model Operation

The EPIC model is applicable to small areas because it assumes the soil, land use, management, etc. are essentially homogeneous. In the vertical direction, it allows up to ten soil layers, with variable thicknesses. It operates on a daily time step. And each time we have an erosion event, the eroded thickness is removed from the soil profile.

Various user options are provided by the EPIC model. Precipitation, temperature, and radiation variables may be input daily or the precipitation can be input and the other two generated. However, for most applications all three are generated. The RCA analysis was a good example of complete weather generation. Another noteworthy feature of the weather generator is its ability to repeat the same weather sequence at a particular site to properly evaluate various management strategies. Any number of weather sequences can be generated at a site to determine the effect of weather variation on a particular strategy. The output of the EPIC model can be obtained on a daily, monthly, or annual basis. We are able to simulate dryland, sprinkler, or furrow irrigation. Also, drainage systems are simulated. The EPIC farm machinery table includes about 100 pieces of equipment and the user can specify which to use in a particular simulation. Fertilizer may be applied at specific dates and rates, or it can be applied automatically as with the RCA version of the model. Water erosion is estimated by three different equations, and any one of the three can be designated as the one that interacts with the other components of the model. Wind erosion is also simulated. The EPIC crop

parameter table is fairly flexible. In its present form, the table includes about 20 crops. In the RCA analysis there were 11, but now we have the flexibility to add any number. The user can add new crops or modify existing parameters as desired. The dates of tillage operations are user specified. There are four methods of harvest options available: (1) grain is removed and the crop is killed, (2) multiple harvest for crops like cotton, (3) hay harvest, and (4) no harvest (destroys winter cover crop, etc.).

There are about 3800 Fortran statements in the EPIC program at this time, the computer cost is about 3 cents per year for overnight turnaround on the Amdahl 470, and the storage requirements are about 300K. By the way, we do have a version of the EPIC model now operating on the IBM PC. The EPIC user package consists of volume one, the model documentation and volume two, the user's manual. The documentation contains details of the equations used to describe various processes in EPIC. The user's manual tells what you need to do to apply the model. We also furnish a computer tape that contains the EPIC program, an example data set, an interactive data entry program, weather generation parameters for about 168 locations, and soils data for 834 soils in the U.S.

Major Components

The major components in the EPIC model are hydrology, weather, erosion, nutrients, plant growth, soil temperature, tillage, economics, and plant environment control. Hydrology deals with surface runoff, both in terms of volume and peak rate. Other hydrologic processes include evapotranspiration, percolation, lateral subsurface flow, and snow melt. The second component, weather, has several input options, as I mentioned earlier. EPIC divides precipitation into rainfall and snowfall. Other weather variables are daily maximum and minimum air temperature, solar radiation, and wind (direction and velocity). The third component, erosion, considers both wind and water.

Three equations are available for estimating water erosion. They are the USLE, the Onstad-Foster modification of the USLE, and MUSLE. For the RCA runs, the Onstad/Foster version of the USLE was selected as the driving equation. To estimate wind erosion, EPIC uses a modification of the Manhattan, Kansas wind erosion model. The fourth component, nutrients, deals with nitrogen and phosphorus. Some of the processes included in the nitrogen component of the model are nitrate loss in surface runoff and leaching, nitrate transport by soil evaporation, upward movement in the soil, organic nitrogen transport by sediment, denitrification, mineralization, immobilization, fixation, crop uptake, and rainfall contribution. EPIC deals with phosphorus in four forms, labile, organic, active mineral, and stable mineral. Some of the processes are the soluble p-loss in the surface runoff and the mineral and organic p-transport by sediment, mineralization, immobilization, sorption, desorption, and crop uptake.

The fifth component, plant growth, uses a general model for all crops. Some of the processes simulated are energy interception; conversion of energy to biomass; division of biomass into roots, above ground biomass, and seed; root growth in the soil layers; sloughing; water use; and nutrient uptake. The crop growth model is constrained by a minimum of three stress factors. These factors range from 0 to 1; 0 indicates no growth and 1 indicates no stress. The stresses are brought about by water, nutrients, and temperature.

The 11 crops originally included in the RCA version of the model are soybeans, alfalfa, corn, grain sorghum, wheat, barley, oats, sunflowers, cotton, pasture, and peanuts. As I mentioned, we have expanded this table to about 20 crops. We plan to become heavily involved in developing an agricultural management model in the near future. This may require expansion to 50 or more crops.

The sixth major component of the model is soil temperature. EPIC estimates the temperature at the center of each soil layer. It's driven by the air temperature, and the transfer from air temperature to soil surface is affected by albido and soil cover.

The seventh component, tillage, simulates ridge height; surface roughness; mixing of the soil layers, nutrients, and flat residue; change in bulk density; and conversion from standing to flat

residue. The eighth model component is plant environment control. It deals with managing drainage, irrigation, fertilization, liming, and pesticides. The final EPIC model component, economics, is a simple accounting of costs and income.

One of our objectives in developing EPIC was to maintain balance among the various components. One way we measure balance among components is the amount of computing time required. We analyzed the time required for each of the major components and found that it ranged from 5 to 15 percent of the total. We believe this narrow range indicates that the model is well balanced.

Future Plans

The major thrust in the future will be toward complex landscapes and extending into large watersheds. The proposed expanded model or combination of models will provide for evaluating offsite as well as onsite erosion effects.

VALIDATION OF EPIC

By C. A. Jones and J. R. Williams

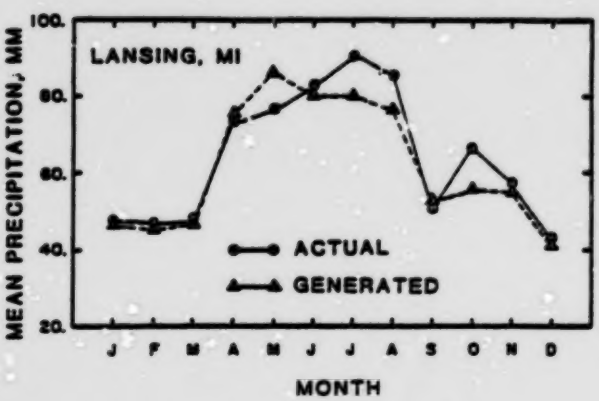
Validation is the key to acceptance and use of complex simulation models like EPIC. However, EPIC simultaneously simulates many physical and biological processes, and it must simulate these processes over a wide variety of edaphic and climatic conditions. It would be very difficult to collect a complete set of weather, hydrology, erosion, soil chemical, and crop growth data needed to validate the model for a single location and a single year. Collection of complete sets of validation data over many years at many locations would be a practical impossibility within the time available for model development. As a result of these practical difficulties we have attempted to validate independently the different major components of the model using experimental and statistical data from many sources. The interaction of these major components over both long and short periods of time was evaluated by experts in the relevant physical and biological sciences.

I would like to discuss the validation of several important components of EPIC: weather generation, runoff, soil erosion, nutrient cycling and maintenance fertilizer requirements, and crop yields. I will then discuss the use of expert analysis in model validation.

Weather Simulation

The weather simulation components of EPIC are based on the work of Clarence Richardson and Arlin Nicks (Nicks, 1984; Richardson, 1981, 1982a,b). These weather simulation models have been validated, and the results have been reported elsewhere (Nicks et al, 1983). The models were developed using measured weather data from locations throughout the U.S. They were validated with data from sites which were not included in their development. Comparisons of measured and simulated mean monthly precipitation and air temperature are given in Figures 1 and 2. In general, the simulated weather sequences for a location are not significantly different than the measured data for the same location. Therefore, we feel that the weather generation procedures in EPIC provide an excellent basis for simulating the effects of climate on soil erosion, crop growth, and other relevant processes.

Figure 1. Mean Monthly Precipitation



Runoff and Soil Erosion

The hydrology component of EPIC is based on the CREAMS hydrology model, which has been thoroughly tested (Williams and Nicks, 198[illegible]; Knisel, 1980).

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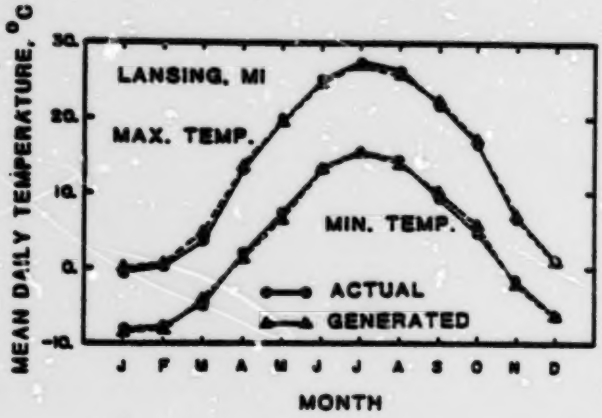
Figure 2. Mean Monthly Air Temperature.



Comparison of measured and simulated runoff and erosion from typical watersheds throughout the U.S. indicate that EPIC produces accurate simulation of these important processes (Tables 1 and 2).

EPIC allows the user to chose one of the three daily water erosion models. These three models are based on the Universal Soil Loss Equation (USLE), the Onstad-Foster modification of the USLE (AOF), or the modified USLE (MUSLE) (Wischmeier and Smith, 1978); Onstad and Foster, 1975; Williams, 1975, 1982). Comparing erosion estimates of the three equations shows that: (a) USLE is highest and MUSLE is lowest in areas with low runoff, (b) MUSLE is highest and USLE is lowest in areas with high runoff, and (c) AOF is generally between the others but usually closer to MUSLE than to USLE.

The wind erosion component of EPIC is a daily version of the annual Manhattan, Kansas wind erosion equation (Woodruff and Siddoway, 1965; Cole et al, 1982). Throughout model development, the wind erosion predicted by EPIC has been compared with that predicted by the annual wind erosion equation. As in the case of water erosion, the results predicted by EPIC are similar to those predicted by the original equation.

Nutrient Cycling and Fertilizer Requirements

As soils erode, both inorganic and organic nutrient transformations are affected. To evaluate these effects, dynamic models of organic carbon and inorganic N and P transformations were developed (Jones et al., 1984a,b; Sharpley et al., 1984). Comparisons of measured and simulated changes in topsoil organic N and P are given in Table 3. These data represent changes which occurred during 28 to 41 years after virgin soil was cultivated. The results suggest that EPIC produces realistic estimates of long-term changes in topsoil organic nutrient concentrations over a wide range of soil and climatic conditions and with several important crop rotations.

Subsoils are usually less fertile than topsoils, and they are often exposed by erosion. Therefore, the model must simulate nutrient cycling in subsoils as well as in topsoils. Long-term measured and simulated changes in subsoil organic P are given in Figure 3. Comparison of similar measured and simulated data from locations throughout the U.S. indicates that the model provides reasonable estimates of subsoil organic N and P concentrations and fertility due to cropping.

Figure 3. Long-term measured and simulated changes in subsoil organic P.

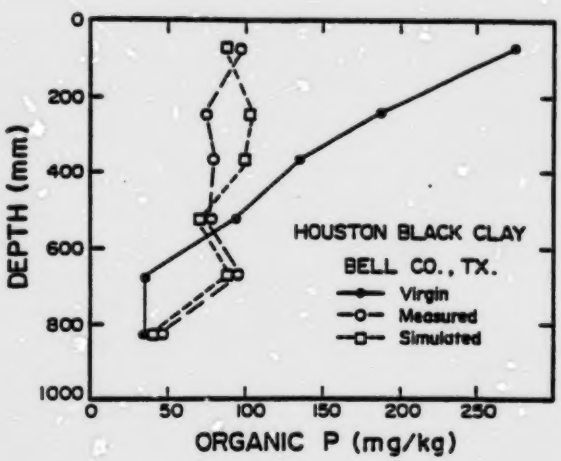


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Table 1. Runoff Model Test Results (Annual-Monthly).

Watershed location	Drainage area (ha)	Length of record (yr)	Average annual					Monthly R2
			Measured		Predicted			
			P (mm)	Q (mm)	Q (mm)	ET (mm)	Percolation (mm)	
SW-2, Riesel, TX	1.04	4	938	159.5	196.3	707	29.0	0.75
SW-12, Riesel, TX	1.29	9	967	229.9	163.8	778	26.7	0.72
Y-6, Riesel, TX	6.47	9	967	145.3	186.4	765	20.3	0.86
Y-8, Riesel, TX	8.29	9	967	170.7	156.0	793	17.3	0.65
21-H, Hastings, NE	1.55	13	580	86.4	93.7	487	0.8	0.41
3-H, Hastings, NE	1.55	14	591	132.6	134.9	458	0.3	0.66
3'H, Hastings, NE	1.55	9	596	120.6	137.4	457	0.3	0.68
PO-1, Watkinsville, GA	2.59	3	1205	221.5	210.8	839	176.5	0.46
PO-2, Watkinsville, GA	1.29	2	1124	150.9	164.1	740	236.2	0.53
104, Coshocton, OH	0.52	8	996	8.9	15.5	823	120.6	0.39
104, Coshocton, OH	0.52	4	899	22.4	29.0	728	120.1	0.92
129, Coshocton, OH	1.04	34	908	21.1	21.3	757	130.8	0.33
130, Coshocton, OH	0.26	21	897	52.8	55.4	729	116.1	0.51
132, Coshocton, OH	0.26	21	897	52.8	55.4	729	116.1	0.51
115, Coshocton, OH	0.52	29	899	43.2	45.2	783	70.1	0.43
110, Coshocton, OH	0.52	29	899	43.2	45.2	783	70.1	0.43
118, Coshocton, OH	0.78	33	928	51.1	56.6	786	85.1	0.53
106, Coshocton, OH	0.52	31	879	52.3	43.9	767	66.8	0.33
192, Coshocton, OH	3.11	28	882	66.3	47.8	767	72.9	0.48
R-5, Chicasha, OK	9.58	8	766	44.7	49.5	694	17.8	0.73
R-7, Chicasha, OK	7.77	8	766	151.9	134.6	614	10.4	0.86
C-4, Chicasha, OK	12.17	9	818	87.6	70.9	745	2.5	0.59
C-5, Chicasha, OK	5.18	9	697	51.3	48.8	643	2.3	0.35
W-6, Cherokee, OK	0.78	19	603	84.6	90.2	509	4.3	0.45
W-7, Cherokee, OK	0.78	19	603	91.2	91.2	509	4.3	0.53
W-13, Cherokee, OK	0.78	7	553	42.2	53.6	497	0.5	0.59
#2, Guthrie, OK	1.29	10	711	106.2	95.0	593	29.7	0.85
W-1, Guthrie, OK	1.04	7	696	17.0	22.6	649	39.9	0.46
W-1, Vega, TX	52.32	5	465	11.4	7.1	456	0.0	0.12
W-2, Vega, TX	38.85	5	471	24.6	20.3	455	0.0	0.27
W-1, Spur, TX	4.66	19	510	49.0	52.1	458	0.0	0.67
W-2, Spur, TX	3.88	19	510	68.1	65.0	445	0.0	0.70
W-3, Spur, TX	4.66	18	511	39.4	43.7	466	0.0	0.72
63105, Lucky Hills, AZ	0.26	10	283	29.0	25.4	262	0.0	0.84
W-1, Ft. Stanton, NM	9.84	10	366	0.5	1.3	380	0.0	0.24
W-2, Ft. Stanton, NM	12.95	10	372	0.0	1.5	379	0.0	0.0001
66001, Moorefield, WV	3.37	9	766	73.7	70.4	649	23.6	0.51
62014, Holly Spr., MS	0.52	3	1155	383.0	405.9	710	46.2	0.80
62014, Holly Spr., MS	0.52	3	857	240.8	246.1	615	30.2	0.65
22003, Guthrie, Ctr., IA	4.92	4	617	29.5	27.2	574	7.1	0.74
Z, Tifton, GA	0.34	6	1287	75.2	77.2	1048	182.1	0.26
A, Sidney, MT	0.78	3	368	43.2	33.5	347	0.0	0.72
W-3, Garland, TX	4.14	3	1042	232.2	226.6	779	21.8	0.84
W-1, Garland, TX	10.10	8	1073	129.8	163.1	805	88.5	0.86
W-3, Tyler, TX	3.11	9	1076	33.3	45.5	811	208.3	0.36
W-5, Tyler, TX	0.78	9	1056	209.0	184.1	785	98.4	0.58
W-4, Tyler, TX	24.09	11	1042	193.8	175.3	770	89.4	0.60

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Table 2. Runoff Model Test Results (Events).

Watershed location	Runoff Volume R^2	Runoff Volume Standard deviation Measured	Runoff Volume Standard deviation Predicted	Peak runoff rate Mean Measured	Peak runoff rate Mean Predicted	Peak runoff rate Standard deviation Measured	Peak runoff rate Standard deviation Predicted
SW-2, Riesel, TX	0.85	18.80	18.80	2.19	1.77	3.17	2.43
SW-12, Riesel, TX	0.69	18.80	13.97	1.75	1.48	2.57	2.38
Y-6, Riesel, TX	6.47	9	967	145.3	186.4	765	20.3
Y-8, Riesel, TX	8.29	9	967	170.7	156.0	793	17.3
2?-H, Hastings, NE	1.55	13	580	86.4	93.7	487	0.8
3-H, Hastings, NE	1.55	14	591	132.6	134.9	458	0.3
3'H, Hastings, NE	1.55	9	596	120.6	137.4	457	0.3
PO-1, Watkinsville, GA	2.59	3	1205	221.5	210.8	839	176.5
PO-2, Watkinsville, GA	1.29	2	1124	150.9	164.1	740	236.2
104, Coshocton, OH	0.52	8	996	8.9	15.5	823	120.6
104, Coshocton, OH	0.52	4	899	22.4	29.0	728	120.1
129, Coshocton, OH	1.04	34	908	21.1	21.3	757	130.8
130, Coshocton, OH	0.26	21	897	52.8	55.4	729	116.1
132, Coshocton, OH	0.26	21	897	52.8	55.4	729	116.1
115, Coshocton, OH	0.52	29	899	43.2	45.2	783	70.1
110, Coshocton, OH	0.52	29	899	43.2	45.2	783	70.1
118, Coshocton, OH	0.78	33	928	51.1	56.6	786	85.1
106, Coshocton, OH	0.52	31	879	52.3	43.9	767	66.8
192, Coshocton, OH	3.11	28	882	66.3	47.8	767	72.9
R-5, Chicasha, OK	9.58	8	766	44.7	49.5	694	17.8
R-7, Chicasha, OK	7.77	8	766	151.9	134.6	614	10.4
C-4, Chicasha, OK	12.17	9	818	87.6	70.9	745	2.5
C-5, Chicasha, OK	5.18	9	697	51.3	48.8	643	2.3
W-6, Cherokee, OK	0.78	19	603	84.6	90.2	509	4.3
W-7, Cherokee, OK	0.78	19	603	91.2	91.2	509	4.3
W-13, Cherokee, OK	0.78	7	553	42.2	53.6	497	0.5
#2, Guthrie, OK	1.29	10	711	105.2	95.0	593	29.7
W-1, Guthrie, OK	1.04	7	696	17.0	22.6	649	39.9
63105, Lucky Hills, AZ	0.26	10	283	29.0	25.4	262	0.0
01, Ft. Stanton, NM	9.84	10	366	0.5	1.3	380	0.0
02, Ft. Stanton, NM	12.95	10	372	0.0	1.5	379	0.0
66001, Moorefield, WV	3.37	9	766	73.7	70.4	649	23.6
62014, Holly Spr., MS	0.52	3	1155	383.0	405.9	710	46.2
62014, Holly Spr., MS	0.52	3	857	240.8	246.1	615	30.2
22003, Guthrie, Ctr., IA	4.92	4	617	29.5	27.2	574	7.1
Z, Tifton, GA	0.34	6	1287	75.2	77.2	1048	182.1
A, Sidney, MT	0.78	3	368	43.2	33.5	347	0.0

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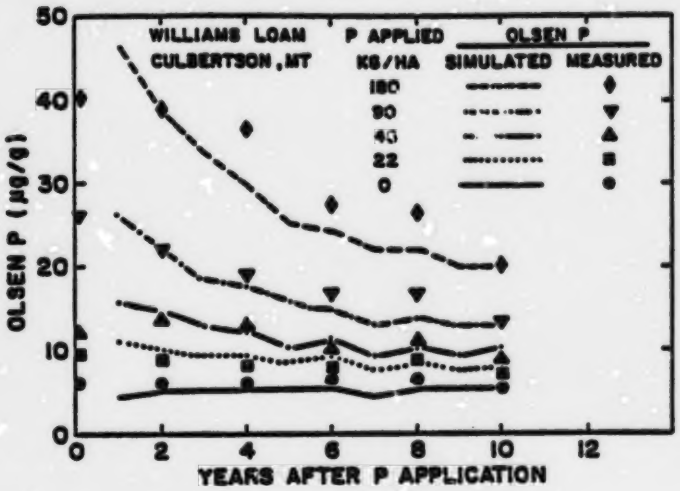
Table 3. Measured and simulated changes in topsoil total N, organic P, and labile P in the Great Plains. Measured data from Haas et al. (1957 and 1961).

Location	Duration	Rotation	Total N			Organic P			Labile P		
				Cultivated			Cultivated			Cultivated	
			Virgin	Meas.	Simu.	Virgin	Meas.	Simu.	Virgin	Meas.	Sumu.
	(yr)		(mg/kg)								
Harre, MT	31	Sp.wheat-fallow	1510	900	1135	157	102	108	11	131	15
Moccasin, MT	39	Sp.wheat-fallow	3000	2050	1787	308	183	169	14	14	20
Dickinson, ND	41	"	2930	1490	1957	292	148	174	10	12	14
Handan, ND	31	"	1600	1160	1172	139	132	97	9	12	7
Sheridan, WY	30	"	1590	1210	1149	120	93	86	12	14	9
Laramie, WY	34	"	1220	820	900	142	91	96	13	24	9
Akron, CO	39	"	1340	800	911	115	82	81	26	45	19
Colby, KS	31	W.Wheat-fallow	1650	1050	952	158	61	92	34	30	27
Hayes, KS	30	W.wheat	2200	1220	1360	174	97	108	11	42	8
Lawton, OK	28	W.wheat	1540	740	904	128	71	73	8	9	8
Delhart, TX	39	Maize	670	420	444	84	39	53	17	13	9
Big Spring, TX	41	W.wheat	600	410	328	55	30	29	12	12	6

Crops, like erosion, reduce soil pools of plant-available N and P. Fertilizer N and P are used to replenish these pools; however, nutrients can be lost by leaching, denitrification, surface runoff, and P "fixation." Shallow sandy soils are particularly susceptible to leaching losses of N. Acid or highly calcareous subsoils exposed by erosion can fix large amounts of fertilizer P. Nutrient losses increase maintenance fertilizer requirements and cost of agricultural production. We have used long-term fertilizer rate experiments conducted on a variety of soils to test EPIC's ability to simulate changes in labile P (Figure 4). The model can also assess and automatically simulate the correction of soil N and P deficiencies by fertilization. The accuracy of this automatic fertilization option was evaluated by comparing simulated maintenance fertilization of wheat and maize with actual maintenance fertilizer recommendations based on crop yield goals in different parts of the U.S. (Figures 5 and 6). This type of testing gives us confidence in EPIC's ability to predict soil erosion. Further testing has confirmed that the model simulates larger maintenance fertilizer

requirements when significant soil erosion occurs, when nutrient losses occur, and when crop yields are very high.

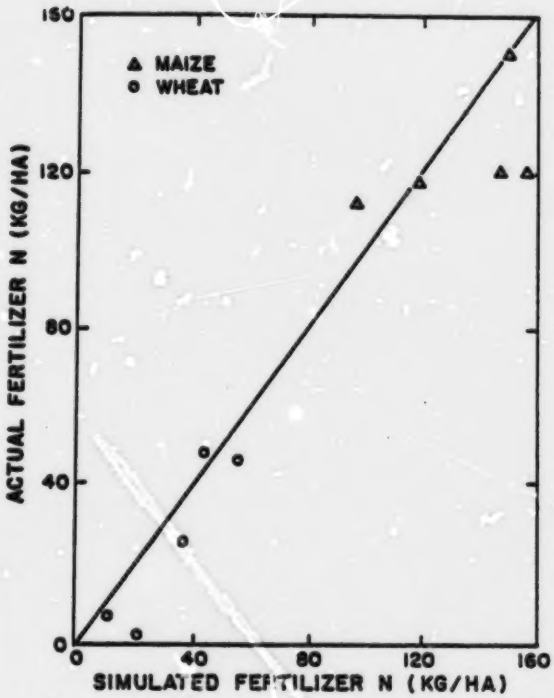
Figure 4. Long-term simulated and measured changes in fertilizer.



Crop Yields

EPIC simulates growth and yield of 11 crops. It would be very difficult to evaluate the accuracy of EPIC's crop growth model for all 11 crops and all combinations of soil, climate, and management under which they are grown. However, we have used data from a variety of sources to evaluate the crop growth model. For major crops such as maize, wheat, soybeans, and grain sorghum we have compared simulated yields with yields measured in specific field experiments. This has allowed us to test model sensitivity to factors such as drought stress and soil fertility (Figures 7 and 8). In addition, we have used data from the SCS Soils-5 data base and the Statistical Reporting Service Objective Yield Survey to verify that mean model yields are similar to farmers' yields throughout the U.S. We feel that in most cases the model produces reasonable estimates of crop yields for a wide variety of crops, soils, climates, and management practices.

Figure 5. Relationship between simulated mean annual fertilizer N application and actual mean annual fertilizer N application (Beach and Adams, 1968) in ten MLRAs in the United States.



Other Validations Processes

As we mentioned earlier, when experimental or statistical data were inadequate to evaluate model performance, we relied on experts for independent evaluations of EPIC's performance. For example, we

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simulated the effects of conventional tillage, minimum tillage, and zero tillage on the amounts of both standing and flat residue for important crop rotations throughout the U.S. These results were sent to tillage experts in the different regions for which simulations were conducted, and their comments were used to make final adjustments to the appropriate model components.

Committees of SCS, ERS, and ARS personnel also made regular evaluations of EPIC's performance. They made numerous recommendations which resulted in improvements in both the simulation model and the data bases used by it.

Figure 6. Relationship between simulated mean annual fertilizer P application and recommended annual fertilizer P application (Ibach and Adams, 1968) in ten MLRAs in the United States.

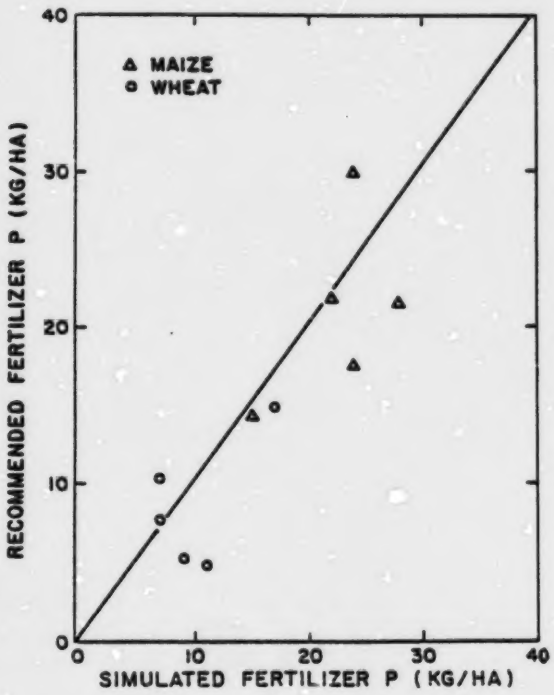


Figure 7. Simulated Corn Yield Comparisons.

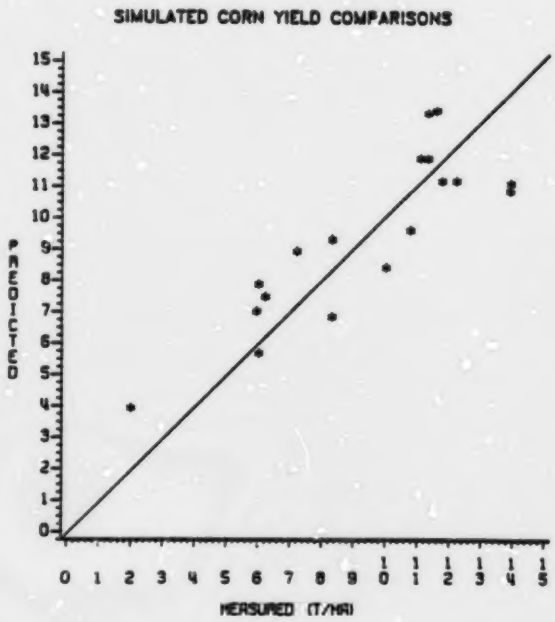
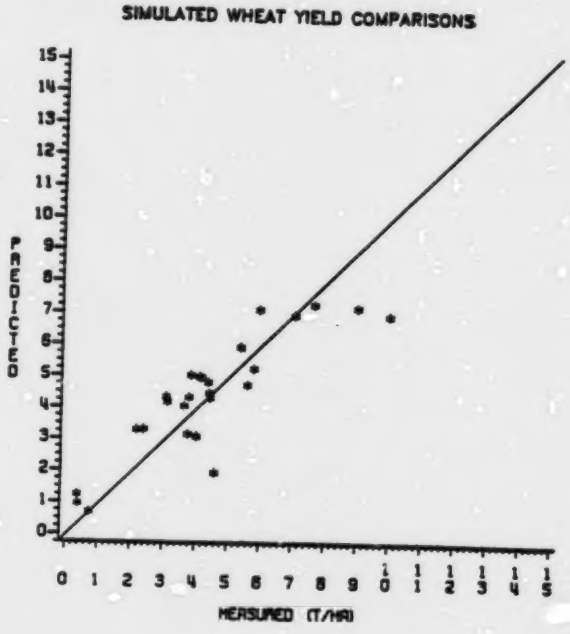


Figure 8. Simulated wheat yield comparisons.



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In conclusion, model validation is a complex and continuing process. In the case of models as complex as EPIC, it requires inputs from many sources--field experiments, statistical summaries, and experts from many disciplines. We have used information from all these sources to evaluate and improve EPIC's performance during the course of its development.

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ASSUMPTIONS SPECIFIC TO THE RCA EPIC MODEL

By John Putman

I will cover assumptions, specifications and limitations with a very broad brush, concentrating on those assumptions that are relevant to limitations. Ralph McCracken mentioned this morning in his presentation the importance of misuse and misrepresentation of model output. I think it's very difficult to avoid sounding negative when you point out limitations. However, it's extremely important to make sure that users of these data understand precisely where the soft spots are. When you build a national model you have to lump an awful lot of things. Its very difficult to convince the people that furnish the data at the state and local level that it's useful after lumping. It's even more

difficult to continually convince them that you're on their side when in every national study we've ever done, we've thrown the data away and started over the next time. So I view this meeting with attention towards the next five years as an omen that we may have learned something. Perhaps this time we'll keep this model and this data set and try to improve it and refine it when we do the next national study.

When I came into the RCA in 1982, I had the feeling that the RCA viewed the EPIC model as a caulking gun, designed to fill holes in the CARD model. I participated in an effort in February 1983 to develop the first EPIC plan of work for the RCA. The plan called for the EPIC model to provide 11 numbers for each productive activity in the CARD model. It wasn't until the November 1984 plan of work for the 1985 RCA Appraisal was written that I had the feeling the RCA switched from a model-driven exercise to a resource-problem-and-evaluation-driven study. In that plan of work EPIC was assigned other analytical objectives. I think this point is an important assumption that we need to keep in mind. Now, let me very quickly go through other assumptions.

1. I think one of the most important things to keep in mind is that EPIC measures the inherent productive capacity of a soil after erosion. It's most sensitive to change in water capacity and physical and chemical structure changes. The model also assumes replacement of all fertility so that there is no fertility loss reflected in the yields.

2. The model does not include annual damages that are associated with the storm events. There is no loss and damage to stands, no replanting, no disruption, and no inundation. None of these very apparent annual damages are built into the production measures.

3. The weather model is built so that it uses the best data source available. As a consequence, you may have temperature and rainfall and wind interpolated from different stations for a centroid county of an MLRA. In addition, the centroid county and that centroid weather may not exactly coincide with a soil that was representative of a particular land group. In the West in particular, reviewers indicated that a particular representative soil did not occur in that particular rainfall area.

4. In some cases, we were forced to substitute the best pedon available for the most representative soil because of the data problems. I think there's a general feeling that the pedons are skewed to the more favorable sites when the samples were collected. Pedons are not associated with slopes and in many cases EPIC used the same pedon for several land classes involving quite different slopes.

5. Because of a great many data problems, we used the 1982 NRI average slope length of all soils in a land group and the state estimates of representative soil slope steepness.

6. For P-factors, we used values from Wishmeyer exactly as they come out of the book. This has a tendency to give nearly all the erosion reduction benefits to contouring. The only residual benefits from terraces are the changes in slope length. As a consequence, we did not run terraces where the slope length was less than the terrace interval. We all know that terraces are installed on landscapes, not a segment of a particular soil that's on a hillside. So you have to recognize that some things are not quite up to "real world" standards yet. Contour strip cropping values are by crop. We had to run EPIC crop by crop. Hence, data for one row crop and one close grown must be averaged together.

CRITERIA FOR SELECTING PEDONS

By Al Hidlebaugh

National Bulletin No. 430-3-5, dated February 8, 1983, Subject: SOILS-Selecting Soil Series and Pedon Data for Use in EPIC Model Runs for the next RCA Appraisal, provided the overall guidance to State Conservationists responsible for selection of

series and pedons with complete soil characterization data.

EPIC-RCA runs were to use eight RCA land groups. These 8 groups are aggregations of the 29 land capability classes and subclasses.

States were asked to select a soil series and pedon with complete laboratory data to represent each RCA land group for each Major Land Resource Area (MLRA) for which they had been assigned responsibility. The RCA-CARD model land groups are shown in Figure 1. These land groups were selected to exhibit a range of erosion hazards and farming practices. The states were also asked to provide a slope length and gradient for each RCA land group for the MLRA(s) they were assigned.

Several lists were provided to each State Conservationist assigned responsibility for at least one MLRA. These lists were (1) the Applied Conservation Effects Survey (ACES), (2) data available from the National Soil Survey Laboratory (NSSL), and (3) the match list provided by the EPIC team.

Figure 1. RCA-CARD Model Land Groups and Associated Class-Sub Class.

RCA Land Group	Class-Subclass
1	I, IIwa*, IIIwa*
2	IIe
3	IIIe
4	IVe
5	IIc, IIIc, IVc
6	IIs, IIIs, IVs
7	IIw, IIIw, IVw
8	V, VI, VII, VIII

*IIw and IIIw soils adequately drained.

The ACES list was initiated in 1977 and updated in 1982. It contains a listing of a soil including slope length and gradient for each land capability class and subclass for each MLRA.

The NSSL (includes predecessor labs) list of available data was restricted to the soil series the state or its neighbors were currently using.

The EPIC generated match list matched available laboratory data from soil series listed on the ACES list with the listing of the RCA land groups for each MLRA. The match list also provided the ACES acreage in cropland of the soil series with laboratory data and it provided the sample numbers of the pedons.

Additional match list of data by taxonomic classification was provided to many states.

National Bulletin No. 430-3-5 provided several special instructions to states. Figure 2 highlights these instructions. Instructions 1 and 2 relate to the emphasis on erosion and productivity. The main reasons for preference of NSSL data are the well documented methods and procedures as well as excellent quality control.

Figure 2. Special Instructions.

1. In RCA 1, preference is to class I over IIwa or IIIwa.
2. In RCA 8, subclass priority is e, s, w, c.
3. Preference is to NSSL data over data from state labs.

Figure 3 highlights the choices state staffs had to consider in the selection process. In many instances the state staffs had to rely on best judgment in the selection process because they had a very limited amount of data available.

The states routed their selections through their respective National Technical Center to the EPIC team in Temple, Texas.

Figure 3. Choices.

1. Choose series and pedon from match list.
2. Select a series and pedon from the same family.
3. Select a series and pedon of a competing series.
4. Best judgment. Select a series and pedon that have similar behavior for plant growth.

How good a job did the states do in selecting pedons that were representative of respective RCA land groups? They did remarkably well, considering the restraints on data availability. Looking at comparison runs for EPIC and the 1982 National Resources Inventory for 11 MLRAs for RCA land group 3 (3e) all but one MLRA appear to have good matches of RKLS/T values. The MLRA's used were 9, 67, 77, 105, 107, 109, 115, 133S, 134, 136N, and 147. In MLRA 9 the EPIC RKLS/T value was 2.9; however, the RKLS/T values for the NRI data were much higher. For the same soil series, 78 percent of the Athena had RKLS/T values of more than 15 and for all of the soils grouped into the land group, 73 percent had RKLS/T values of 6 or more. Figure 4 shows the matches for MLRAs 67 and 77.

Figure 4.--Representative EPIC Soil Series Relative to NRI Data for RCA Land Group 3 (3e).

MLRA	Source	Percent Series of all land in RSG	RKLS/T	Soils
	EPIC		3.8	Norka
67	NRI	100%	6	Norka
	NRI	99%	6	all soils
77	EPIC		0.7	Amarillo
	NRI	99.5%	2	Amarillo
	NRI	96.9	2	all soils

PEDONS - HOW DEVELOPED

By Wes Fuchs

The previous discussion related to the history and the selection of the pedons (Figure 1). I want to touch on some history prior to the selection of the RCA land group pedons and why it led into some of the data crunching that we did later. The National Soil Survey Laboratory had about 5,000 pedons in a computer data base that the EPIC team could access. There were about 5,000 other pedons that were in Soil Survey Investigation Reports (SSIR) that were not in a computer.

Figure 1. Representative Soils.

History	CNI
	ACES
	NRI
Preliminary	Load characterization data
	Provide SCS for selection
Selection	8 resource soil groups
	Characterization data
	Provide estimates
Loading	Key new data and estimate
	Access Soil 5 data
	Generate values
	Data gaps and edit
Evaluation	Erosion factors
	Production factors

The EPIC team loaded the SSIR pedons so that about 10,000 pedons were available to select from. The selection process started from the ACES list, which included all soils previously designated by states (Figure 2). The state responsible for that MLRA had to choose one soil with characterization data for each RCA group, either from one that was listed in ACES or from another soil. For instance, in MLRA 112, RCA 2, the Dennis series was listed as having some data, however the state chose to use a Dennis pedon that wasn't on this list. In RCA 1, instead of choosing one of the soils listed the

Figure 2. Sample ACES list of soils designated by states.

MATCHES FOR RCA SOIL SERIES VS PEDONS 0:16 TUESDAY, FEBRUARY 8, 1983, 182

MLRA=112 RCA = 1

CLASS	STATE	NAME	ACRES	NUM		SAMPLENO	PEDONNO	YEAR	FLAG	%	Length
1	20	Reading	115	57120045			1857				
1	40	Okemah	89	56240111	1	3582935835	4718		SSIR		
1	40	Okemah	89	56240111	2	3583635842	4719		SSIR		
1	29	Verdigris	52	56040131	2	3599536001	4739		SSIR		
2WA	29	Hartwell	51							15	800
2WA	20	Verdigris	51	56040131	2	3599536001	4739		SSIR	1.5	to be
2WA	40	Verdigris	51	56040131	2	3599536001	4739		SSIR		Class
3WA	20	Osage	51	57320001	4	1447014477	1816		SSIR		I
3WA	29	Osage	51	57320001	4	1447014477	1816		SSIR		
3WA	40	Osage	51	57320001	4	1447014477	1816		SSIR		

MLRA=112 RCA=2

CLASS	STATE	NAME	ACRES	NUM		SAMPLENO	PEDONNO	YEAR	FLAG	%	Length
2E	29	Barden	248								
2E	20	Dennig	425	S5340145	20					2.0	400
2E	40	Dennis	265		37	3569535702	4701		SSIR		

MLRA=112 RCA=3

CLASS	STATE	NAME	ACRES	NUM		SAMPLENO	PEDONNO	YEAR	FLAG	%	Length
3E	29	Bolivar	329								
3E	40	Dennis	71	S5340145	20	3570335710	4701		SSIR		
3E	40	Dennis	71	S5340145	23	3571135718	4702		SSIR	3.0	300
3E	20	Kenoma	631	S7320001	2	1471714725	1847		SSIR		

MLRA=112 RCA=4

CLASS	STATE	NAME	ACRES	NUM		SAMPLENO	PEDONNO	YEAR	FLAG	%	Length
4E	29	Barco	127								
4E	40	Bates	15	S6240063	3	3562235627	4691		SSIR		
4E	40	Bates	15	S6240063	4	3562835634	46592		SSIR	5.0	200
4E	40	Bates	15	S7320037	1	1456914574	1828		SSIR		
4E	20	Kenoma	121	S7320001	2	1472614736	1848		SSIR		

state marked out Mason and chose Reading. It is of the same taxonomic classification which the state felt was a more representative pedon. The state was asked to provide the slope length and the slope percent that was most representative of the series in the RCA group. States were provided an index of all pedons that had soils data (Figure 3). They were also provided a list of soils with data by taxonomic classes (Figure 4). Where ACES soils were lacking data, they could select a comparable soil that had characterization data available. States were asked to give the maximum soil depth such as to fragipan or bedrock. If the data didn't have 15 bar water, organic matter or pH they were to provide best estimates.

The soil selections were then loaded with the best estimates and brought out for edit in laboratory format (Figure 5). We should have had some numbers under column 20, the coarse fragment column. We only send the soil to the lab for analysis, not the rocks and stones. Consequently, the laboratory seldom prints the amounts of coarse fragments in the soil. We have to read that in the description part, and add it on. I filled in data gaps and made corrections.

After this editing, the soils were placed in a direct access file (Figure 6). Quite a bit of this information comes direct from the SOILS-5. We get the classification, taxonomic codes, and wind and water soil erodability from the SOILS-5. The maximum soil depth in most instances is from the SOILS-5 averaging the depth of bedrock. Quite a few things are calculated from SOILS-5 information, such as the curve number from the hydrologic group, the soil albido, the water content and the initial organic and labile phosphorus. A lot is calculated, and a lot comes straight from the data itself.

How much editing and changing was needed in loading the more than 800 pedons? A sample from A through about 16 percent of the total pedons indicates only about 2 percent of the pedons that we received from the states needed no change (Figure 7). Bulk density, sum of bases, water capacity, cation exchange capacity, and soil depth needed the most editing or changes. Some of these were because CEC may have been run by some sum of cations and the model runs on CEC by ammonium acetate. To test pedon selection for fit, we chose a dozen MLRA's (Figure 8). These are indicated on the map of the major land resource areas of the United States. We have been looking at these in relation to their erosivity as well as their productivity. For instance, we run RKLS for MLRA 136 north. The distribution comes out of the NRI (Figure 9). For all the class 3E land, we find that RKLS is peaking somewhere around 60. In looking at only Cecil in RCA 3 we find it also peaks about the same for RKLS (Figure 10). We also compared RKLS divided by T. In most instances we're in the right ball park, the right box. One other thing we've been looking at besides RKLS, and RKLS divided by T, is the productivity of the soil. We are relating productivity as if a particular soil and a soil family have some similarity. As an example, Brownfield was listed in the NRI as the most extensive cropland soil in RCA group 8 in MLRA 77 (Figure 11). Brownfield was the series they chose for this RCA group. In MLRA 107, Marshall was seventh from the top in RCA 1 and the taxonomic class was sixth from the top. However, the fertility classification system (FCC) (proposal by Stan Buol, et al), having to do with the kind of soil (such as loamy surface, soil with a loamy subsoil, well drained and deep) fits well in this category. For the most part, our people did a good job of selecting the kind of soil that represents that part of the country.

Figure 3. Sample list of pedons containing soil data.

INDEX

SERIES	YEAR	PEDON	SAMPLE		SURVEY		SOURCE
KIESER	1940	3520	7178	7184	S56MT111	5	SSIR
KEITH	1979	73	363	369	57BNE123	049	NSSL
KEITH	1940	1791	4276	4284	S57KS109	1	SSIR
KEITH	1940	1792	4285	4293	S57KS109	2	SSIR
KEITH	1940	2120	6795	6802	64NE045		SSIR
KEITH	1940	2121	6903	6810	S54NE087	5	SSIR
KEITH	1940	2266	7789	7795	S58NE049	5	SSIR
KEITH	1940	2267	7796	7802	S58NE049	6	SSIR
KEITH	1940	2268	7803	7809	S54NE087	2	SSIR
KEITH	1940	2269	7810	7816	S54NE087	e	SSIR
KEITH	1940	2270	7817	7825	S57NE105	3	SSIR
KEITH	1940	2271	7826	7834	S57NE105		SSIR
KEITH	1940	2407	8826	8834	S57SD113	1	SSIR
KEITH	1940	2408	8835	8843	S57SD113	2	SSIR
KEITH	1940	3349	6714	6719	S53WY015	3	SSIR
KEITH	1940	3878	9702	9710	S63CO115	11	SSIR
KEKAWAKA	1980	521	2938	2943	S80CA 45	5	NSSL
KELK	1981	241	1248	1254	S80NV 7	803	NSSL
KELLA	1940	2716	8632	8640	S71MT013	2	SSIR
KELLER	1981	619	3674	3676	S741L009	006	NSSL
KELLNER	1940	1536	2068	2073	S57WI097	1	SSIR
KELLNER	1940	1537	2074	2078	S57WI097	2	SSIR
KELLY	1980	391	2110	2110	S80V2107	000	NSSL
KELSALL	1982	622	3267	3272	S82AK100	006	NSSL
KELTYS	1980	221	1177	1187	S80TXC05	007	NSSL
KEMPSVILLE	1978	313	1667	1682	SA78VA159	065	NSSL
KENAI	1940	626	4643	4654	S60AK	1	SSIR
KENANSVILLE	1980	487	2723	2729	S80SC051	001	NSSL

Figure 3. Continued.

INDEX

SERIES		YEAR	PEDON	SAMPLE		SURVEY		SOURCE
KENASTON		1940	71	501	508	S58ND 7	2	SSIR
KENASTON		1940	72	509	516	S58ND 7	3	SSIR
KENASTON		1940	73	517	525	S58ND 7	6	SSIR
KENASTON		1940	74	526	531	S58ND 7	2	SSIR
KENASTON		1940	75	532	538	S58ND 51	1	SSIR
KENAT		1940	625	4635	4642	S57AK	4	SSIR
KENDRICK		1940	5242	9387	9393	S12 1	065	SSIR
KENESAW		1981	154	786	790	S80NE081	146	NSSL
KENESAW		1940	2122	6811	6816	S76NE041	12	SSIR
KENESAW		1940	2272	7835	7841	S54NE079	1	SSIR
KENESAW		1940	2273	7842	7847	S54NE081	1	SSIR
KENNAN		1980	56	249	252	S79W1073	001	NSSL
KENNAN		1983	398	1812	1818	S82W1073	005	NSSL
KENNAN	T	1978	506	2947	2954	S78W1115	002	NSSL
KENNAN	T	1978	507	2955	2963	S78W1115	003	NSSL
KENNAN	T	1978	508	2964	2970	S78W1115	004	NSSL
KENNEBEC		1940	2124	6824	6830	S73NE109	3	SSIR
KENNER		1940	4091	1275	1282	S71LA051	1	SSIR
KENNER		1940	4092	1283	1288	S71LA051	6	SSIR
KENNER		1940	4093	1289	1292	S71LA051	13	SSIR
KENNER	T	1940	4083	1223	1230	S71LA051	4	SSIR
KENNEY		1940	4456	4078	4084	S54TX073	90	SSIR
KENNEY		1940	4457	4085	4090	S54TX073	91	SSIR
KENNEY LAKE		1981	684	4082	4090	S81AK260	021	NSSL
KENNEY LAKE SATELLI		1982	155	7987	797	S81AK612	021	NSSL
KENOMA		1940	1847	4717	4725	S70K6001	2	SSIR
KENOMA		1940	1848	4726	4736	S70MI051	1	SSIR
KENT		1940	1984	5084	5091	S70MI051	1	SSIR

Figure 4. Sample of Taxonomic Data.

TAXONOMIC CLASS

MATCH OF ALL SUPPLY AND DEMAND SOILS WITH SOILSS 0:34 WEDNESDAY, MARCH 9, 1983

FAMILY=MUDAR AA 96 34 2 16 2

MLRA	RCA	CLASS	STATE	NAME	ACRES	NUM		SAMPLENO	PEDONNO	YEAR	FLAG
109	4	4E	29	SHELBY	191	S5619001	5	1136311371	1462	.	SSIR
109	4	4E	29	SHELBY	191	S5619001	6	1137211380	1463	.	SSIR
109	4	4E	29	SHELBY	191	S5619001	7	1138111386	1464	.	SSIR
109	4	4E	29	SHELBY	191	S5619001	8	1138711394	1465	.	SSIR
109	4	4E	29	SHELBY	191	S5619001	9	1139511401	1466	.	SSIR
109	4	4E	29	SHELBY	191	S5619001	10	1140211407	1467	.	SSIR
109	4	4E	29	SHELBY	191	S5519165	3	1140811414	1468	.	SSIR
109	4	4E	29	SHELBY	191	S5319165	3	1141511420	1469	.	SSIR
109	4	4E	29	SHELBY	191	S7120087	4	1182714834	1860	.	SSIR
109	4	4E	29	SHELBY	191	S7120087	5	1483514844	1861	.	SSIR

FAMILY=MUDAR AA 96 46 2 18 2

MLRA	RCA	CLASS	STATE	NAME	ACRES	NUM		SAMPLENO	PEDONNO	YEAR	FLAG
112	4	4E	40	BATES	15	S6240063	3	3562235627	4691	.	SSIR
112	4	4E	40	BATES	15	S6240063	4	3562835634	4692	.	SSIR
112	4	4E	40	BATES	15	S7320037	1	1456914574	1829	.	SSIR

FAMILY=MUDAR AA 100 34 2 16 2

MLRA	RCA	CLASS	STATE	NAME	ACRES	NUM		SAMPLENO	PEDONNO	YEAR	FLAG
105	6	2S	55	DAKOTA	23	S 77WI-111-001		78P 832- 838	158	78	NSSL
105	6	2S	55	DAKOTA	23	S 77WI-017-003		78P1107-1112	218	78	NSSL
105	6	2S	55	DAKOTA	23	S7027047	2	1350613544	1711	.	SSIR
958	6	3S	17	LORENZO	7					.	

FAMILY=MUDAR AA 100 34 2 16 2

MLRA	RCA	CLASS	STATE	NAME	ACRES	NUM		SAMPLENO	PEDONNO	YEAR	FLAG
	.		.	BROADWELL	.	S6617107	3	1603616044	2012	.	SSIR
	.		.	BROADWELL	.	S6617107	3	1603616044	2012	.	SSIR
	.		.	DINSDALE	.	S6019013	1	1071610726	1399	.	SSIR
	.		.	DINSDALE	.	S6019075	2	1072710738	1400	.	SSIR
116A	1	1	5	HEALING	.					.	SSIR
958	2	2E	17	PLANO	374	S6255021	2	1248912500	1585	.	SSIR
958	1	1	55	PLANO	202	S6255025	2	1250112512	1586	.	SSIR
76	1	1	20	READING	83	S7120045	2	1480614811	1857	.	SSIR
76	1	1	20	READING	83	S7120045	2	1480614811	1857	.	SSIR
	1		1	RICHWOOD	.	S5655063	3	1256412570	1594	.	SSIR
	1		1	SAYBROOK	.	S4817197	4	2189321896	2773	.	SSIR
	1		1	SAYBROOK	.	S6717089	4	2216822177	2808	.	SSIR
107	2	2E	29	SIBLEY	282	S 79MO-047	-003	80P 565- 570	115	80	NSSL
108	2	2E	17	TAMA	2556	S4817129	2	2193021938	2777	.	SSIR

Figure 5. Sample of edit format used to develop pedons.

Soil No. 73

Series: Berks Pedon: 5378 Soils 5: 1739 SSIR

Sampled As: Loamy-Skeletal, Mixed, Mesic Typic Dystrochrept IOCDY AA 50 34 2 1C 2

Location No. 5942-077 -002 Sample Nos. 40A 40354 - 40357 Date: 03/08/84

U.S. Department of Agriculture
Soil Conservation Service
National Soil survey Laboratory
Lincoln, Nebraska

Old Sample Nos. - 4 Max Soil Depth 840

General Methods 1B1A, 2A1, 2B

-1-- -2-- -3-- -4-- -5-- -6-- -7-- -8-- -9-- -10- -11- -12- -13- -14- -15- -16- -17- -18- -19- -20-

HZN NO.	DEPTH (CM)		HORIZON	(- - -TOTAL - - -) CLAY LT .002 002	SILT .05 -.05	SAND -2	(- -CLAY- -) FINE LT .0002	CO3 LT .002	(- -SILT- -) FINE .002 -.02	COARSE .02 -.05	(- - - - - -SAND- - - - - -) VF .05 -.10	F .10 -.25	M .25 -.50	C .5 -1	VC 1 -2	(-COARSE FRACTIONS(MM)-) 2 -5	5 -20	WEIGHT - - - - 20 -75	.1- 75	(2MM) WT PCT O WHOLE SOIL
				- - - - - - - - - - - - PCT OF 2MM (3A1) - - - - - - - - - - - -												- PCT OF 75MM(3B1)-				
1	0-	28	AP	22.0	38.1	39.9					1.5	2.8	4.7	10.6	20.3	--	--	--	38	20
2	28-	48	B21	20.8	32.3	46.9					1.6	3.0	5.3	11.6	25.4	--	--	--	45	40
3	48-	64	B22	19.5	40.5	40.0					3.2	5.4	7.4	10.8	13.2	--	--	--	37	40
4	64-	84	C1	13.3	50.0	36.7					5.5	7.4	7.5	8.7	7.6	--	--	--	31	40

HZN NO.	ORGN C	TOTAL N	EXTR TOTAL P	S	(- - DITH-CIT - -) EXTRACTABLE FE	AL	MN	CEC	(RATIO/CLAY) 15 BAR	(ATTERBERG) - LIMITS - LL	PI	(- BULK DENSITY -) FIELD MOIST	1/3 BAR	OVEN DRY	COLE WHOLE SOIL	(- - -WATER CONTENT - -) FIELD MOIST	1/10 BAR	1/3 BAR	15 BAR	WRD WHOLE SOIL
	- - - - - - -PCT OF 2MM - - - - - - -									PCT	0.4MM	- - G/CC - - -			CM/CM	- - -PCT OF 2MM - -				CM/CM
1	2.05	0.190							0.35					1.35					7.8	
2	0.38	0.090							0.39					1.40					8.1	
3	0.31	0.080							0.46					1.40					8.9	
4	0.17	0.070							0.85					1.40					11.3	

HZN NO.	(- NH4OAC EXTACTABLE BASES -) CA	MG	NA	K	SUM BASES	ACID- ITY	EXTR AL	(- - - -CEC - - -) SUM CATS	NH4- OAC	AL BASES + AL	SAT	-BASE SAT- SUM	NH4 OAC	CO3 AS CACO3 2MM	RES. OHMS /CM	COND. MMHOS /CM 81	(- - - -PH - - -) CACL2 .01M	H2O
	- - - - - - - - - - - - MEQ / 100 G - - - - - - - - - - - -											- - - - -PCT - - - -					1:2	1:1
1	6.9	1.1	0.1	0.3	8.4	7.8		16.2	13.0			52						5.6
2	4.4	1.0	0.1	0.1	5.6	4.7		10.3	8.2			54						6.0
3	4.3	0.5	0.1	0.1	5.0	4.0		9.0	7.2			56						6.3
4	3.3	0.7	0.1	0.1	4.2	3.8		8.0	6.4			52						6.5

Figure 6. Sample of pedon data as used in the RCA.

EPIC SOILS IN DIRECT ACCESS FILES

SOIL NUMBER: 73

SOIL SERIES NAME: BERKS PEDON: 5378 SOILS 5: 1939 SOURCE: SSIR

	YEAR	STATE	COUNTY	SAMPLE
SURVEY NUMBER:	59	42	77	2

	ORDER	SUBGRP	PART SIZE	MINEROL	REACT	SOIL TEMP	OTHER
TAXONOMIC CODE:	IOCDY	AA	50	34	2	16	2

TAXONOMIC DESCRIPTION: LOAMY-SKELETAL, MIXED, MESIC TYPIC DYSTRCCHREPT

	FROM	TO		FROM	TO
SAMPLE NUMBERS:	40354	- 40357	OLD LAB NUMBERS:		- 4

SOIL ERODIBILITY:	0.17	CURVE # - ROW:	85.00	SOIL ALBEDO:	0.13
WIND SOIL ERODIBILITY:	108.00	CURVE # - GRAIN:	83.00	MAXIMUM SOIL DEPTH:	840.00

	SOIL LAYER NO					
	1	2	3	4	5	6
DEPTH (MM)	10.00	150.00	280.00	480.00	640.00	840.00*
BULK DENSITY (T/M--3)	1.35*	1.35*	1.35*	1.40*	1.40*	1.40*
WILTING PT (MM/MM)	0.091*	0.091*	0.091*	0.074*	0.058*	0.047*
MIN FIELD CAP (MM/MM)	0.214*	0.214*	0.214*	0.163*	0.143*	0.119*
SAND (%)	39.90	39.90	39.90	46.90	40.00	36.70
SILT (%)	38.10	38.10	38.10	32.30	40.50	50.00
IRON (%)	0.00	0.00	0.00	0.00	0.00	0.00
COARSE FRAGMENT (%)	20.00*	20.00*	20.00*	40.00*	40.00*	40.00*
INITIAL NO3 (G/T	10.00*	10.00*	5.00*	5.00*	5.00*	5.00*
INITIAL ORG N (G/T)	1900.00	19.00.00	1900.00	900.00	800.00	700.00
INITIAL LAB P (G/T)	30.00*	30.00*	10.00*	10.00*	10.00*	10.00*
CROP RESIDUE (KG/HA)	33.95*	433.66*	517.53*	403.11*	162.06*	44.01*
PH H2O (1:1)	5.60	5.60	5.60	6.00	6.30	6.50
SUM BASES NH4OAC (MEQ/100G)	8.40	8.40	8.40	5.60	5.00	4.20
INITIAL ORG C (%)	2.06	2.06	2.06	0.38	0.31	0.17
INITIAL CACO3 (%)	0.00	0.00	0.00	0.00	0.00	0.00
CDEF OF LIN EXT (%)	0.00	0.00	0.00	0.00	0.00	0.00
CEC NH4OAC (MEZ/100G)	13.00*	13.00*	13.00*	8.20*	7.20*	6.40*
SOIL TEXTURE	L*	L*	L*	L*	L*	L*
HORIZON CODE	AP	AP	AP	B21	B22	C1

Figure 7. PERCENT OF PEDONS NEEDING ADDITION OR CHANGE BY SOIL PROPERTY

PERCENT	PROPERTY
67	Bulk Density
56	Sum of Bases
35	Available Water Capacity
34	Cation exchange Capacity
34	Depth
16	Organic Carbon
14	Coarse Fragments
13	pH
11	Texture
2	No change

Figure 8. MLRA to test pedon selection process (9, 67, 77, 101, 105, 107, 109, 115, 133S, 134, 136N, 147).

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Figure 9. Distribution by Resource Land Group (RSG) for MLRA 136N.

(EROS = RKLS)

TABLE OF RSG by EROS

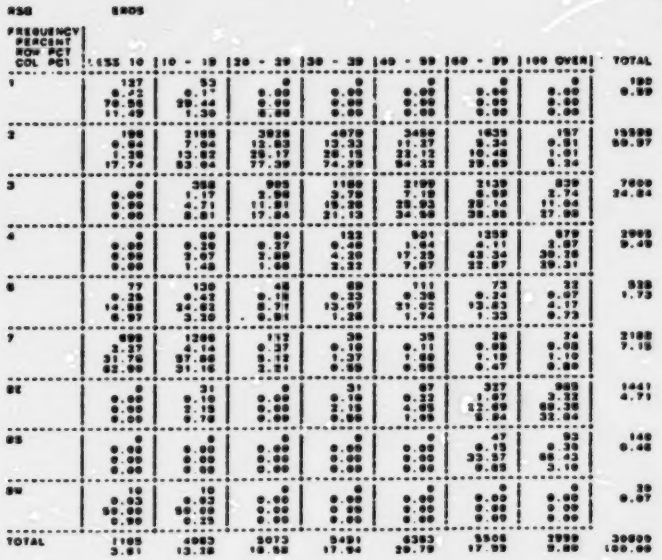

Figure 10. Distribution of RKLS by RSG Land Group Soil Series used in RCA/EPIC for MLRA 136N Cropland. Acres in 100's.

(EROS = RKLS)

Table of RSG by EROS

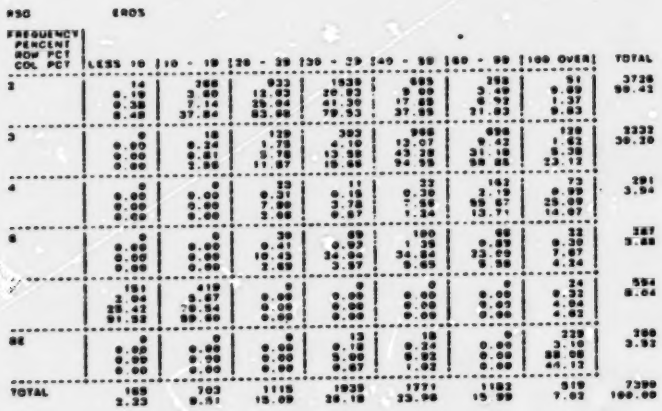

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Figure 11. Sample of most extensive cropland soil by Series.

			EVALUATION				
			EROSION		PRODUCTION		
			EPIC	NRI	NRI	EXTENT	
MLRA	RSG	SOIL	RKLS T	RKLS T	SOIL	TAXON CLASS	FCC
77	2	Acuff	0.5	0.8	3	3	2
	3	Amarillo	0.7	1.0	1	1	1
	4	Amarillo	1.8	1.0	2	1	1
	5	Olton	0.7	0.9	-	1	1
	6	Pullman	0.8	0.9	1	1	1
	7	Randall	0.6	1.0	1	1	1
	8	Brownfield	0.5	1.3	1	1	1
107	1	Marshall	1.7	1.8	7	6	2
	2	Marshall	4.3	5.6	2	1	1
	3	Marshall	13.3	18.5	1	1	1
	4	Monona	42.3	35.1	2	2	1
	6	Sarpy	1.8	1.6	1	1	1
	7	Zook	1.7	2.0	4	1	1
	8	Ida	102.0	47.4	3	3	1

CROP BUDGETS FOR THE 1985 RCA APPRAISAL

By Dave Post

Background

The development of the crop budgets to be used in the 1985 RCA Appraisal was initiated as a result of data problems that surfaced during the 1980 RCA process. The CARD/RCA Interregional Linear Programming Model was the major model used in the 1980 RCA analysis. Various components constituted the model, one of which was crop tillage. The 1980 RCA model incorporated three tillage systems: fall plow conventional tillage, spring plow conventional tillage, and reduced tillage. The crop budgets developed for the three tillage systems came from the Firm Enterprise Data System (FEDS). A major concern about the three tillage system concept used was that no consistency existed on what constituted reduced tillage. The level of tillage could vary from a chisel plow-disk combination to using only a no-till planter. This variation could occur regionally and also by crop. Because of the consistency problems, the decision was made that for the 1985 RCA Appraisal, crop tillage would be composed of four tillage systems: fall plow conventional tillage, spring plow conventional tillage, conservation tillage, and zero tillage.

Crop Budget Data Collection Process

Initially, the intent was to develop the appropriate crop budgets using FEDS and the Soil Conservation Service (SCS) Crop Budget Generator. After reviewing both data sets, a number of gaps existed. Not enough information was in these data files to develop crop budgets by crop, tillage system, and Major Land Resource Area (MLRA). As a result, SCS National Bulletin No. 240-2-2, dated March 2, 1982, requested that each SCS state office provide current data on the machinery complements that constituted each of the four tillage systems defined by crop and for both dry and irrigated land, where applicable. The crops were: barley, corn for grain, corn for silage, cotton, legume and nonlegume hay, oats, sorghum for silage, soybeans, sunflowers, wheat, and peanuts. The state had the option to develop the crop budgets to represent the entire state: if they felt regional differences occurred on the types and kinds of machinery compliments that composed a particular system, some substate breakdown could be used. One possibility would be by MLRA. The states also had the option of using existing budgets or developing new crop budgets to meet the request. Information also was requested on typical crop yields and any other information that they felt was pertinent.

Most of the information received from the states had to be computerized. For the next nine months, the data that were sent in were coded, key punched, edited, reviewed, and analyzed. The objective was to develop a crop budget, where applicable, by crop, dryland or irrigated, and MLRA. During the internal review process, a number of data gaps were

discovered in the crop budget file. Budgets were missing either for a crop or tillage system, or both, by MLRA. From the data provided, crop budgets were developed to fill these gaps. SCS National Bulletin No. 240-3-1, dated January 21, 1983, requested the SCS state offices to review information on machinery used by selected cropping alternatives. The information sent to each state included two sets of crop budgets. Set A represented the crop budgets developed from the information that the state provided under National Bulletin 240-2-2. Set B represented the crop budgets selected from Set A that were to be used in the 1985 RCA Appraisal. In Set B, the crop budgets were by crop, tillage system, and MLRA. Since most MLRAs crossed state boundaries, a crop budget for a given tillage system was selected from the state with the largest acreage in that MLRA. Where MLRAs traverse a number of states (such as MLRA 133A), attempts were made to disaggregate the MLRA and have several crop budgets represent a given crop and tillage system. The states were to review these budgets for consistency and reasonableness.

A number of changes and corrections in the crop budgets were made from this review process. After incorporation of these changes and corrections, a final set of crop budgets was developed. A copy of the budgets was sent to Temple, Texas, to be used in the Erosion Productivity Impact Calculator Model (EPIC). Problems surfaced immediately that had not been foreseen. The two major problems were: (1) The EPIC model operated on Julian days and, as a result, sequencing of tillage practices was critical. The crop budgets sent to Temple had not taken this into consideration. (2) Crop budgets were missing for some crops and tillage systems. The main gap was in hay where both establishment and maintenance budgets were needed. Earlier edit checks had missed these and other data voids. These and other problems meant that additional editing plus additional information on missing crop budgets were needed.

The first major problem of sequencing of tillage practices could be handled between the staffs at Iowa State and Temple, Texas. The second major problem of developing the missing crop budget information was more difficult. The decision was made to meet with representatives from each of the four SCS National Technical Centers (NTC's) separately and develop an approach on gathering the missing budget data for each region. Meetings with the NTC representatives took place between October 1983 and January 1984. Representatives of the Economic Research Service (ERS) attended.

The approaches taken on obtaining the missing crop budget data varied by NTC. The method used depended on the amount of crop budget information needed. One NTC basically did all the work at the NTC level, whereas another NTC went back to the states requesting the missing budget information. The amount of data collected on crop budgets by the four NTCs was significant. The data collected were incorporated into the crop budget generator for use in EPIC and the RCA/CARD L.P. Model.

Two items surfaced during the meetings with the NTC representatives. The first was that guidelines had been developed on what constituted conventional tillage, conservation tillage, and zero tillage. If the amount of soil cover from residue left on the surface after planting was less than 30 percent, the tillage system was defined as conventional tillage. If the amount of soil cover from residue left on the surface after planting was greater than 30 percent but less than 85 percent, the tillage was defined as conservation tillage. If the amount of soil cover from residue left on the surface after planting was greater than 85 percent, the tillage system was defined as zero tillage. Based on these definitions, all crop budgets were reviewed at the NTC level for consistency. Any that failed to meet the criteria were redone by the NTC. Also, at this time, the terminology on denoting the two conventional tillage systems changed. Conventional tillage fall plow was changed to clean till without winter cover while conventional tillage spring plow was changed to clean till with winter cover. No change occurred for conservation and zero tillages.

The second item had to do with additional information needed from the NTCs for the EPIC and the RCA/CARD models. During the meetings, information on irrigation, wind erosion, and terracing costs were collected. Also, review of the crop rotation file and double cropping took place.

Other Data Files

The data collected on machinery complements for the various crop budgets is but one part of developing a crop budget. Costs, names, yields, units, prices, etc., are also needed in the crop budget. The following files were used in developing the final set of crop budgets:

1. Parameter File. This includes indices, prices, costs, taxes, insurance, and other comparable data. The File used is the 1980 FEDS Parameter File.

2. Name File. This lists the names of the inputs in the crop budget. This File is a combination of the FEDS and SCS name files.

3. Machinery Name and Complement Files. This includes the machinery name and machinery complement such as size, horsepower, width, etc. This File is a combination of FEDS and SCS machinery complement files.

4. Unit File. This lists the various units used, such as pounds, tons, bushels, bales, etc.

5. Yield File. This lists representative crop yields based on data for 1979-1981 from the Statistical Reporting Service county level data.

6. Price File. This lists prices received and paid by farmers from the FEDs files.

Conclusion

The crop budgets to be used in the 1985 RCA Appraisal are no doubt the most complete set of crop budgets in the country. Roughly 3,000 budgets have been developed. These budgets constitute the major crops grown in this country. The crops used in this analysis comprise nearly 94 percent of the cropland acreage used. Refinement of these crop budgets will need to continue; crop budgets for crops not in the system will need to be added to meet future anticipated data needs.

WEATHER MODEL FOR RCA EPIC

By Clarence Richardson

Weather has a dominant influence on the crop production of an area and on the erosion that results from a particular management system. The EPIC model requires daily weather data for each site being evaluated. The need to make long (50 years or longer) EPIC runs for many sites for the RCA analysis made the use of historical weather data impractical, if not impossible. A weather generation model was used to provide daily weather data for EPIC. The basic structure of the weather model and the way the model was used in the RCA appraisal will be described in this paper.

Weather Generation Description

The weather data required by EPIC are daily values of precipitation, maximum temperature, minimum temperature, solar radiation, wind speed, and wind direction. The weather generation model was designed to generate long samples of these weather variables with the same statistical characteristics as the actual weather for the site. Precipitation and wind are generated independent of the other variables. Maximum temperature, minimum temperature, and solar radiation are generated conditioned on whether the day is wet or dry. Mathematics of the weather generation procedure are given in Richardson (1981). Only an overview of the procedure will be given here.

Precipitation

Precipitation is modeled using a Markov chain to generate the occurrence of wet or dry days and a skewed normal distribution (Nicks, 1974) to generate the amount of precipitation on wet days. With the Markov chain model, the probability of rain on a given day is conditioned on the wet or dry status of the previous day. The probability of a wet day given a wet day on the previous day and the probability of wet day given a dry day on the previous day must be defined. The skewed normal distribution has three parameters that must be defined. The parameters are the mean, the standard

deviation, and the skewness coefficient of precipitation amount on days with rain. The values of the five precipitation model parameters change during the year at most locations. In the weather generator, each of the five precipitation parameters are held constant for each month but are varied from month to month. The parameters have been determined by month for approximately 150 locations in the United States.

Temperature and Solar Radiation

The procedure used for generating daily values of maximum temperature, minimum temperature, and solar radiation is described by Richardson (1981). The procedure is designed to preserve the correlation among the three variables and the serial correlation (persistence in time) of each variable. The mean and standard deviation of temperature and radiation are conditioned on whether a wet or dry day was generated. The seasonal characteristics of the temperature and radiation parameters are described with a Fourier series. The values of the Fourier coefficients have been calculated for locations in the United States and contour maps of the parameters have been developed (Richardson and Wright, 1984).

Wind

The wind component provides for the generation of daily values of wind speed and direction using the procedure described by Richardson (1982). Wind speed is generated using a two-parameter gamma distribution. The gamma distribution parameters are defined from monthly values of the mean and standard deviation of daily wind speed. The mean and standard deviation of wind speed are determined from the Climatic Atlas of the United States (U.S. department of Commerce, 1968). Wind direction is generated using an empirical cumulative probability distribution of wind direction. Monthly percentages of days with wind from each of 16 directions are obtained by location from the Climatic Atlas. These 16 percentages are assembled to form a cumulative probability distribution for each month.

Precipitation and Temperature Correction

Usually the data generated with the procedures described above will have monthly means that are very close to the means obtained from observed data. In some cases there will be differences caused by the temporal and spatial smoothing, topographic features, or other factors. The weather generator provides for correction of these differences using observed mean monthly values. The correction procedure provides for correction of generated daily values such that monthly means from the generated data will compare very closely with the monthly means from the observations.

Application of Weather Generation to RCA/EPIC

The precipitation, maximum and minimum temperature, and solar radiation generation parameters for locations in the United States were assembled into a data bank. A numerical interpolation procedure was developed that would calculate the generation parameters for a selected site from the latitude and longitude of the site. For the RCA/EPIC runs a central county was selected for each MLRA. The generation parameters were then determined using the latitude and longitude of the center of the county.

The mean monthly precipitation amounts for use in applying the correction procedure were obtained for the NOAA Weather Division in which the county was located. These monthly precipitation amounts were obtained from NOAA weather tapes. The mean monthly maximum and minimum temperatures to be used in the correction procedure were obtained from the Climatic Summary of the U.S. (U.S. Department of Commerce, 1964) for a station in the county. If no station within the county was given in the Climatic Summary, the data for the nearest station given in the Climatic Summary were used.

The wind generation parameters were obtained from the Climatic Atlas of the United States (U.S. Department of Commerce, 1968). The mean annual and mean monthly wind speeds and the percent of days with wind from each of 16 directions for each month are given for approximately 100 stations in the United States. This wind data was digitized and assembled into a data base. The data for the station nearest the central county for the MLRA were used to generate daily wind for the RCA/EPIC runs.

Summary

The weather generation procedure developed for RCA/EPIC enables the generation of daily weather data for selected sites that have the same statistical characteristics as actual weather for the site. Use of the weather generator greatly facilitates the use of EPIC to make long simulations at many sites. The parameters of the weather model can be determined from the latitude and longitude of each site. Mean monthly data that can be used to correct generated values to known monthly means can be obtained from published sources and data bases that have been assembled. Data generated with the weather model have been compared to actual weather data at numerous sites (Richardson and Wright, 1984; Richardson, 1985; Nicks and Richardson, 1985; and Hanson and Richardson, 1983).

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VALIDATION PROCEDURES USED FOR EPIC IN THE 1985 RCA APPRAISAL

By Thyrele Robertson

Background

The EPIC model had peer review in ARS and had been tested in 17 Major Land Resource Areas across the nation prior to being run for the RCA Appraisal process.

Review and validation of the EPIC model by SCS for the appraisal began in May 1984. The procedures were worked out with representatives of each agency and are listed below:

1. EPIC would be run by groupings of Land Resource Regions.

2. SCS staff from National Headquarters and National Technical Centers would meet with ARS and ERS staffs at Temple to review the estimates for erosion and related yield impacts; nitrogen, phosphate, and lime requirements; and changes in pedon characteristics, water requirements, and relationship of dryland to irrigated yields.

3. Adjustments in the model would be made provided that they would not affect the interrelationships of the model.

4. SCS technical review staff would consist of soil scientists, agronomists, and irrigation specialists.

Basis for Validation

Yields estimated by EPIC were compared to Soils 5 yield data, Ag-Census data, and personnel knowledge by the reviewers. Erosion estimates were related to knowledge of soils and USLE factors. All data were reviewed for reasonableness of the estimates based on experience and knowledge.

Results of the Validation Procedures

The review procedures identified some problems with the model that were corrected. Other problems could not be corrected without seriously affecting the schedule for delivery of the output required for the Appraisal process. The problems that could not be corrected were noted and are part of the SCS proposal for our next 5-year development plan.

In general, the validation teams felt that the model's performance is adequate for a first time effort. Relationships of erosion and yield among RCA land groups appear to be correct in terms of direction of erosion/yield impacts. Absolute amounts of erosion and changes in yield could not be verified.

The general feeling of the review team is that EPIC is working well and will be a better model if it incorporates the recommendations resulting from the review/validation process. At this point, it is the best general model available to estimate erosion/yield impacts by tillage and conservation/management practices throughout the United States.

At this point, EPIC accounts for only part of the erosion impacts on yields. Some of the impacts not included in EPIC are listed below.

1. Plant damage due to wind erosion and deposition.

2. Reduction in plant stand due to washout of seedbed, gully formation, and lower germination rates from encrustation of the soil surface.

3. Lower water availability due to higher runoff rates on eroded soils.

4. Plant death from prolonged dry periods and reduced soil moisture-holding capacity.

EROSION-PRODUCTIVITY INDEX SIMULATOR

By John Putman

I'm happy to report that EPIC works. In fact, EPIC worked so well that we had to develop another modeling system to process and evaluate the output.

The system is called the Erosion-Productivity Index Simulator (EPIS) model. It performs four major functions: (1) it processes EPIC output to storage tapes, microfiche, and EPIS input; (2) it expands information and analyses from a sample of EPIC simulations into a baseline (1980) information system covering all resource/management/conservation alternatives relevant to the RCA analysis; (3) it measures the impact of erosion on future productivity and fertilizer requirements; and (4) it maintains these data for a continuing RCA appraisal and other program and policy analyses.

Let me start by discussing EPIC output to illustrate the need for EPIS. EPIC summarizes and reports data in two forms--monthly and annually. Figure 1 shows a sample of EPIC output for a single year in a simulation. The shaded portion is the monthly (OM) data set and the unshaded part is the annual (OY) output. For each of the 12,000 simulations made for the 1985 RCA, 100 of these tables were generated. The OM data set consists of about 90 measurement variables. This means that we have a data base of 90 items for 12 months in each of the 100 years for each of 12,000 simulations--approximately 1.3 billion numbers. These data are currently backed off on 125 tapes, and 12,000 micro-fiche in Temple. We started with a handful of microfiche; admiring how much data each held. When we started on the second filing cabinet of micro-fiche we began to realize the magnitude of our problem.

The OY data sets are also stored on tapes. We have processed the OY data sets into crop sequence data sets with selected variables retained for RCA analysis. In other words, an OY data set or a 100-year simulation of the rotation corn-corn-hay-hay is divided into 4 crop sequence data sets (corn-corn, corn-hay, hay-hay, hay-corn) of 25 years each.

Data needs for EPIC simulations were determined by CARD model rotation requirements. Figure 2 illustrates how the CARD rotations were used to formulate five EPIC rotations which included all of the crops and most of the crop sequence needed. Crop sequences from each set were matched and interpolated to provide a merged crop sequence list by MLRA. This constitutes the crop sequence data base that we use in the RCA. Each crop sequence, however, must be replicated for four tillages and, where appropriate, 3 conservation alternatives. That is 12 tillage-conservation combinations for, in the example shown, 32 crop sequences. Thus, in this single MLRA, 384 crop-management alternatives are required per soil (Figure 3). If all eight soils are present, the number of data sets required expands to 3,072. Assuming this MLRA is typical of the other 167, the potential number of data sets approaches a half million. The actual number, however, turned out to be closer to a quarter of a million.

Running 250,000 EPIC simulations was an impossible task, so we devised a scheme to develop a sample of EPIC simulations and expand these to meet total needs. This is why we developed 12,000 simulations (Figure 4). From this sample, we generated an information system which provided approximately 250,000 production alternatives for the CARD model.

Yields from all non-eroding simulations were pooled to provide data sets by three subclusters--crop sequence, tillage, and land groups. Conservation measures were tested and found to have no impact on productivity and therefore are not included. A program called DUMTEST measured the difference within and among subset means using dummy regression procedures. Each set of indices is ranked around a preselected base (or intersect) scaled to a unit value of 1.0. The coefficients express a measure of relative productivity (RP) within each of the three categories and the multiplicative interaction among the three groups. Figure 5 illustrates RP indices.

Erosion estimates were computed from the ratio of LKSCP between the EPIC sample simulation and the KLSCP for alternatives being predicated. The same procedure with appropriate variables was repeated for wind erosion.

The method we used to estimate the impact of erosion on productivity and plant nutrients is based upon a concept introduced by Perrons (1983). This method pairs two simulations, identical except that the erosion control practice (P) factor is used to bracket the extremes in potential erosion rates. This is accomplished by setting the P factor in the AOF equation at one and zero to represent no erosion control (P=1) and perfect conservation or no erosion (P=0), respectively. The model ran normally, except in one case it removed no soil. In effect, the results compare production and nutrient use on a pedon held constant in its initial state to a pedon that's gradually eroding away over a hundred years. It worked beautifully.

We matched the two outputs year-by-year and computed an annual series of eroded/noneroding yield ratios and fertility requirements (Figure 6). These annual series provide a profile of the impact of erosion on the productivity and fertilizer needs of a particular soil. Everyone knows this loss relationship is not linear. The relationship varies greatly from year to year and among soils. Unfortunately, we could not find a non-linear equation that we could trust to fit 12,000 samples without manual edits. There was no way we could manually edit each and determine a "good" fit. Consequently, all loss ratios being used in this analysis are linear.

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MLRA: 120 ROT: : TILL: SPLW RCA: 3 CLASS: 3E SERIES: ZANESVILLE LAT: 37.75 LONG: 87.00 DATE: 01/16/85 TIME: 11:28:12

3

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YR	
TMX													18.84	TMX
TMN													7.42	TMN
RAD													376.68	RAD
RAIN			56.52	57	87.43	48.99	142.82	48	85.20	82.33			1086.83	RAIN
SNOW			1.55	0.0	0.0	0.0	0.0	0.0	0.0	0.0			123.87	SNOW
Q			18.90	12.1		3.40		6.64	12.2	10.10			384.20	Q
SSF			0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			0.0	SSF
PRK													100.65	PRK
ET													644.66	ET
EP													101.10	EP
SW														SW
USLE													36.51	USLE
AOF													67.05	AOF
EI													306.00	EI
Y													88.92	Y
C													0.20	C
PET													1436.00	PET
YW													0.31	YW
RN													8.86	RN
YON													78.91	YON
YNO3													58.51	YNO3
SSFN													0.0	SSFN
PRKN													3.72	PRKN
MNN													132.89	MNN
IMN													39.47	IMN
ON													0.0	ON
NFIX													0.0	NFIX
UNO3													65.86	UNO3
HMN													32.63	HMN
YP													17.38	YP
YAP													0.61	YAP
UPP													8.30	UPP
MNP													26.08	MNP
IMP													11.75	IMP
PLAB														PLAB
PMIN														PMIN
TNO3														TNO3
HU														HU
LAI														LAI
RD														RD
RTWT														RTWT
DM														DM
RSD														RSD
STD														STD
TMP													3230.35	TMP

DATA SETS

OM

OY

337.65 ALS = 1.50 EK = 0.41 WK = 126.00 USLE = 205.19 TWE = 1.12 TEMD = 328.78 ERTH = 21.86

CROP YLD = 1139. KG/HA DM = 3336. KG/HA IRGA = 0. MM CAW = 365. MM MX RD = 885. MM NFIX = 0. KG/HA LIME = 0.0 T/HA
HI = 120.49 FP = 20.29 FNSD = 0.0 FNPL = 120.49 PRSD = 315.14 PSTD = 0.18
STRESS FACTORS (DAYS & VALUE) -- WATER = 18 0.82 N = 0 0.0 P = 0 0.0 TEMP = 72 0.68

0. KG/HA DM = 0. KG/HA IRGA = 0. MM CAW = 315. MM MX RD = 0. MM NFIX = 0. KG/HA LIME = 0.0 T/HA
21.84 FP = 9.36 FNSD = 0.0 FNPL = 21.84 PRSD = 66.12 PSTD = 0.04
FACTORS (DAYS & VALUE) -- WATER = 18 0.80 N = 0 0.0 P = 0 0.0 TEMP = 71 0.82

Figure 1. Sample of OM and OY Data Sets.

42

Figure 2. Development of Rotations.

CARD

83B	D		ENL	NLH	NLH	NLH
83B	D		ELH	LHA	LHA	LHA
83B	D	1	COT	COT	CGR	
83B	D	1	COT	CGR	SGR	
83B	D	1	CGR	SGR		
83B	D	1	CGR	CUT		
83B	D		OAT	NLH	NLH	NLH
83B	D		SGR	OAT	NLH	NLH NLH
83B	D	1	SGR	WWT		
83B	D	1	SGR	SGR	SGR	COT
83B	D	1	SGR	SGR	CGR	
83B	D	1	SGR	SGR	COT	
83B	D	1	PEA	PEA	SGR	
83B	D	1	PEA	BAP	SGR	
83B	D	1	PEA	WWT		
83B	D	1	COT	SGR		

EPIS

COT		SGR		SGR	WWT	WWT	
CGR		SGR	WOT	WOT	WWT	WWT	
CGR	WOT	WOT	LHA	LHA		LHA	
WBR	WWT	WWT		NLH	NLH	NLH	WBR
PNT		PNT	WWT	WWT		SGR	

CUCUP	PRCRP
CGR	COT
CGR	SGR
COT	CGR
COT	COT
COT	SGR
LHA	LHA
NLH	NLH
NLH	WOT
PNT	PNT
PNT	SGR
PNT	WWT
SGR	CGR
SGR	COT
SGR	NLH
SGR	PNT
SGR	SGR
SGR	WBR
SGR	WWT
WBR	PNT
WOT	NLH
WOT	SGR
WWT	PNT
WWT	SGR

CUCRP	PRCRP
CGR	LHA
CGR	WWT
COT	WWT
LHA	LHA
LHA	WOT
NLH	NLH
NLH	WWT
PNT	PNT
PNT	SGR
SGR	CGR
SGR	COT
SGR	SGR
SGR	WWT
WBR	NLH
WOT	CGR
WOT	SGR
WWT	PNT
WWT	SGR
WWT	WBR
WWT	WOT

MERGED

CUCRP	PRCRP
CGR	COT
CGR	LHA
CGR	SGR
CGR	WWT
COT	CGR
COT	COT
COT	SGR
COT	WWT
LHA	LHA
LHA	WOT
NLH	NLH
NLH	WOT
NLH	WWT
PNT	PNT
PNT	SGR
PNT	WWT
SGR	CGR
SGR	COT
SGR	NLH
SGR	PNT
SGR	SGR
SGR	WBR
SGR	WWT
WBR	NLH
WBR	PNT
WOT	CGR
WOT	NLH
WOT	SGR
WWT	PNT
WWT	SGR
WWT	WBR
WWT	WOT

Figure 3. Data Matrix.

Crop Sequence Tillage and Conservation

CUCRP	PRCRP	SR				CT				CS				TR			
		F	S	C	Z	F	S	C	Z	F	S	C	Z	F	S	C	Z
CGR	COT	X	X	X	X	X	X	X	X					X	X	X	X
CGR	LHA	X															X
CGR	SGR	X															X
CGR	WWT	X															X
COT	CGR	X															X
COT	COT	X															X
COT	SGR	X															X
COT	WWT	X															X
LHA	LHA	X															X
LHA	WOT	X															X
NLH	NLH	X															X
NLH	WOT	X															X
NLH	WWT	X															X
PNT	PNT	X															X
PNT	SGR	X															X
PNT	WWT	X															X
SGR	CGR	X															X
SGR	COT	X															X
SGR	NLH	X															X
SGR	PNT	X															X
SGR	SGR	X															X
SGR	WBR	X															X
SGR	WWT	X															X
WBR	NLH	X															X
WBR	PNT	X															X
WOT	CGR	X															X
WOT	NLH	X															X
WOT	SGR	X															X
WWT	PNT	X															X
WWT	SGR	X															X
WWT	WBR	X															X
WWT	WOT	X	X	X	X	X	X	X	X					X	X	X	X

12 TILL./CON.

X

32 CRP. SEQ.

384 CRP/MGT ALTERNATIVES PER SOIL

Figure 4. Sample of Data Matrix.

EPIS SAMPLE

ROTATION	RCA	NE FSCZ	SR FSCZ	CT FSCZ	CS FSCZ	TR FSCZ
1	1		X			
	2	XXXX	XXXX	X		
	3	X	X	X		X
	4	X	XXXX	X		
	5		X			
	6		X			
	7					
	8	X	X	X		X
3	1	X				
	2	XXXX	XXXX			
	3	X	X			
	4	X	X			
	5	X				
	6					
	7					
	8	X	X			

Figure 4. Continued.

EPIS SAMPLE

ROTATION	RCA	NE FSCZ	SR FSCZ	CT FSCZ	CS FSCZ	TR FSCZ
4	1	X				
	2	XXXX	XXXX			
	3	X	X			
	4	X	X			
	5	X				
	6					
	7					
	8	X	X			
5	1	X				
	2	XXXX	XXXX			
	3	X	X			
	4	X	X			
	5	X				
	6					
	7					
	8	X	X			
10	1	X				
	2	XXXX	XXXX			
	3	X	X			
	4	X	X			
	5	X				
	6					
	7					
	8	X	X			

NE = No Erosion; SR = No Erosion Control;
CT = Contour; CS = Stripcropping; TR = Terrace
F = Clean Till--No Winter Cover;
S = Clean Till With Winter Cover;
C = Conservation Tillage; Z = No Till

non-linear equation that we could trust to fit 12,000 samples without manual edits. There was no way we could manually edit each and determine a "good" fit. Consequently, all loss ratios being used in this analysis are linear.

This sample shows Erosion Productivity (EP) loss ratios fitted with linear, squared, and cubed regression equations. You'll notice that you can get quite different patterns from these four soils

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Figure 5. Relative crop productivity by current crop, previous crop, tillage and land group.

MLRA 4

CURRENT CROP

		CGR	CSL	COT	FAL	LHA	NLH	PNT	SBR	SGR	SOT	SOY	SSL	SUF	SWT	WBR	WOT	WWT
	CGR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0000	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	CSL	0.0	1.0000	0.0	0.0	0.0	0.0	0.0	1.0000	0.0	1.0000	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P	COT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
R	FAL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
E	LHA	0.0	1.0000	0.0	0.0	1.1500	0.0	0.0	1.0000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
V	NLH	1.0000	1.0000	0.0	0.0	0.0	1.0000	0.0	1.0000	0.0	1.0000	0.0	0.0	0.0	0.0	0.0	0.0	0.0
I	PNT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
O	SBR	0.0	1.0000	0.0	0.0	1.0000	1.0000	0.0	1.0000	0.0	1.0000	0.0	0.0	0.0	0.0	0.0	0.0	1.0000
U	SGR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
S	SOT	0.0	0.0	0.0	0.0	1.0000	1.0000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SOY	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C	SSL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
R	SUF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
O	SWT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P	WBR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	WOT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	WWT	0.0	0.0	0.0	0.0	1.0000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T	FPKW	1.0000	1.0141	0.0	0.0	0.9998	0.9977	0.0	1.0005	0.0	1.0032	0.0	0.0	0.0	0.0	0.0	0.0	1.0000
I	SPLW	1.0000	1.0000	0.0	0.0	1.0000	1.0000	0.0	1.0000	0.0	1.0000	0.0	0.0	0.0	0.0	0.0	0.0	1.0000
L	CTIL	1.0000	0.9938	0.0	0.0	1.0023	1.0104	0.0	1.0001	0.0	1.0011	0.0	0.0	0.0	0.0	0.0	0.0	0.9996
L	ZTIL	1.0000	0.9931	0.0	0.0	1.0045	1.0165	0.0	1.0066	0.0	1.0002	0.0	0.0	0.0	0.0	0.0	0.0	1.0013
L	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
A	2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N	3	1.0000	1.0000	0.0	0.0	1.0000	1.0000	0.0	1.0000	0.0	1.0000	0.0	0.0	0.0	0.0	0.0	0.0	1.0000
D	4	1.0000	1.0000	0.0	0.0	1.0000	1.0000	0.0	1.0000	0.0	1.0000	0.0	0.0	0.0	0.0	0.0	0.0	1.0000
	5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
G	6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
R	7	1.0000	1.0000	0.0	0.0	1.0000	1.0000	0.0	1.0000	0.0	1.0000	0.0	0.0	0.0	0.0	0.0	0.0	1.0000
P	8	1.1500	1.1500	0.0	0.0	1.1500	1.1500	0.0	1.1500	0.0	1.1500	0.0	0.0	0.0	0.0	0.0	0.0	1.2996

NOTE: INTERACTIONS AMONG CROP SEQUENCE, TILLAGE, AND LAND GROUP COMBINATIONS ARE MULTIPLICATIVE.

(Figure 7). Some soils lose very consistently. Others hold fairly constant until they crash at some critical limit of remaining soil. The reason I selected the one in the lower right corner is to illustrate the fitting problem. Note that the squared and cubed lines ended up in opposite directions.

When you compute yield and fertilizer ratios such as the ones I've shown as a function of time, they are dependent on every assumption that was associated with that particular 100-year simulation. As I previously mentioned, simulations of every combination of assumptions were impossible. As a result, we had to find a measure of erosion impact that was less assumption dependent. This was accomplished by computing yield and fertility change as a function of accumulated erosion.

Figure 8 shows an example of total erosion compared with time on the horizontal axis. In the upper graph, the same soil eroding at three different rates because of slope appears to be loosing productivity differently. Note, however, when the loss is graphed as a function of soil loss rather than time, the curves are much closer together. Loss coefficients expressed as a function of tons of erosion may be used for any projected year and any rotation/tillage/conservation assumption. The EPIC loss coefficients require only an estimate to total tons or a rate of loss and a time period. They are independent of the assumptions that caused the loss. This approach makes the coefficients usable for everybody and provides great flexibility.

Figure 6. Eroding-Noneroding Yield Ratios

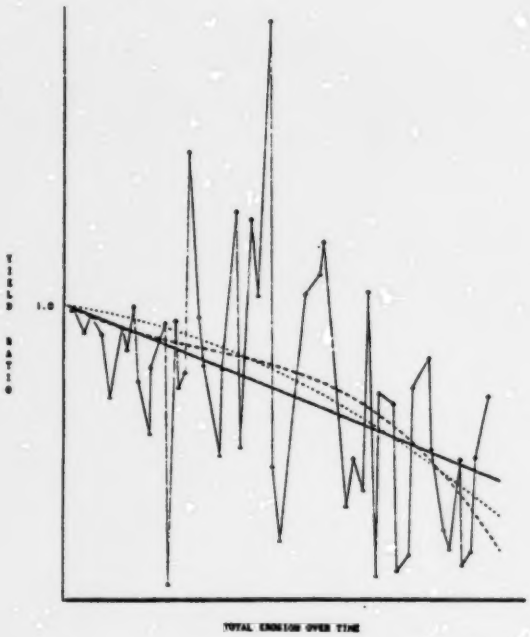

Figure 7. Eroding-Noneroding Yield Loss Ratios for four soils by Type of Regression Equation.

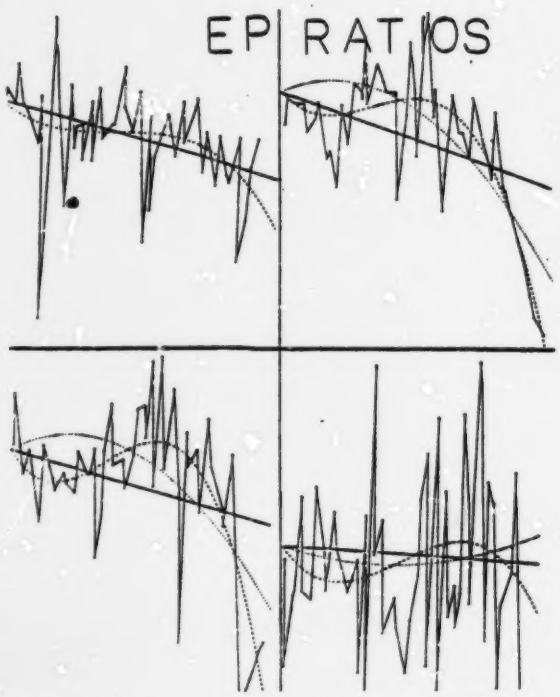

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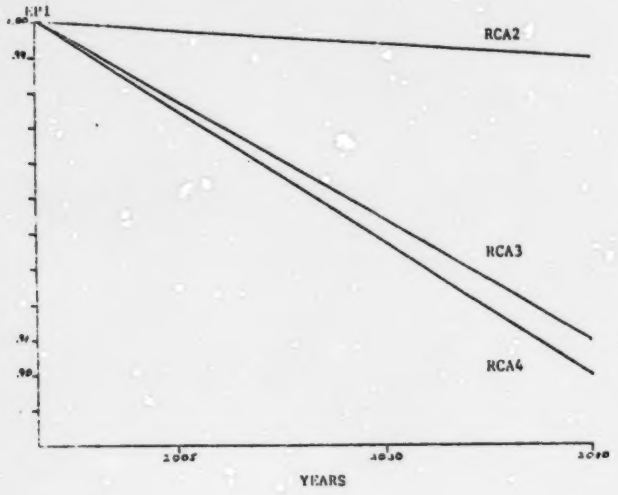
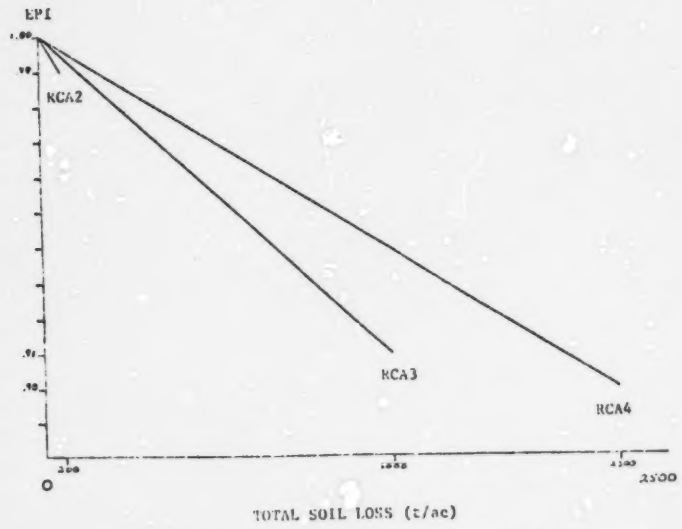
Figure 8. Erosion Productivity Index by years and by rate--Clarion Soil.





EROSION AS A FUNCTION OF TILLAGE, MANAGEMENT, AND SOIL CHARACTERISTICS

By Wes Fuchs

In this three-part discussion we wish to cover some of the outputs related to erosion, productivity, and regression coefficients. In the erosion arena we have four different tillage practices: fall plowing, spring plowing, conservation till, and zero till. We had about 17 different crops and many combinations of rotations. We had straight row, contouring, contour strip, terrace, and wind strip. We had 168 MLRA's with up to 8 RCA groups. Multiplying all these together indicates output possibilities of about one million. We cannot review all this with you, one line at a time. I've got a few examples that represent a lot of condensing. In Figure 1 we are looking at RCA group 3 in the LRR's in the nation, rather than looking at every MLRA. We combined low residue row crops, such as cotton, peanuts, and soybeans. We combined high residue row crops, such as corn for grain and sorghum for grain. Small grains, such as wheat, barley, and oats--fall or spring planted--are also combined. These are then divided into fall plow, spring plow, conservation till, and zero till; expected erosion rates then should be in declining order. The output is tons of erosion for the mean of all the runs in the LRR. For high residue row crops with fall plow, for example, we note LRR N has one of the highest erosion rates. For spring plow with low residue row crops some of the highest erosion rates are in LRR A and N. You'll notice we've got a declining order for fall plow to spring plow to conservation till to zero till. We get less erosion as we put more practices on the land.

Looking at the same information a slightly different way, we omitted the high residue and low residue row crops (Figure 2) and looked at conventional tillage which is primarily straight row, conservation tillage, and with terracing. For conventional tillage, this shows that most of our erosion on fall plow is occurring in LRR's M through U, excluding R. These LRR's which get a lot of rainfall also have the highest erosion rates for the less severe tillage practices.

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Looking at erosion rates another way, we have merged EPIC rates with cropping pattern acres from the recent NRI (Figure 3). In LRR M we find 84 million acres of high residue row crops with an erosion rate of 20 tons.

This is the same data by NRI rates rather than EPIC rates (Figure 4). Comparing the high residue row crops, we find about 17 tons per acre rather than 20 tons in LRR M on about 84 million acres.

This summary table (Figure 5) sandwiches the NRI average erosion rate by RCA groups between erosion rates for minimum and maximum conservation treatment from EPIC. Conventional tillage is straight row, and terraced includes conservation tillage and terraces where applicable. For instance, the average erosion rate from the NRI for RCA 3 in LRR N is 9 tons, the EPIC output for conventional tillage is 15 tons and for terraced and conservation tillage is 5 tons. In most cases, our conventional tillage is on the high side and our terrace and conservation tillage is on the low side of the average erosion rate from NRI.

In summary, the erosion outputs from EPIC are extensive and this is only a summary to indicate the kinds of outputs that are available.

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Figure 1. EPIC-Tillage Conservation Erosion Rates.

Resource Soil Group 3

LRR	CROP GROUP																			
	FAL TILLAGE				MAY TILLAGE				MRC TILLAGE				LRC TILLAGE				SMG TILLAGE			
	FLPW	SPLW	TILC	TILZ	FLPW	SPLW	TILC	TILZ	FLPW	SPLW	TILC	TILZ	FLPW	SPLW	TILC	TILZ	FLPW	SPLW	TILC	TILZ
	USLE	USLE	USLE	USLE	USLE	USLE	USLE	USLE	USLE	USLE	USLE	USLE	USLE	USLE	USLE	USLE	USLE	USLE	USLE	USLE
A	.	.	.	.	4	3	3	1	.	.	.	.	43	39	31	14	21	17	9	2
B	5	4	3	1	2	1	1	1	.	.	.	.	.	.	.	.	2	2	1	2
C	15	15	13	8	4	4	3	1	.	.	.	.	43	12	10	4	21	5	4	1
D	6	4	5	5	1	1	1	1	1	1	1	1	43	1	1	1	21	3	3	1
E	5	3	2	1	1	1	1	1	6	5	4	2	43	.	.	.	21	2	1	1
F	2	2	1	1	1	1	1	1	4	4	3	1	43	2	1	1	21	1	1	1
G	6	6	5	3	1	1	1	1	5	5	3	1	43	6	4	3	21	2	2	1
H	8	7	6	4	1	1	1	1	7	6	5	2	43	2	2	1	21	3	3	1
I	.	.	.	.	2	1	1	1	9	7	7	3	43	7	6	3	21	2	1	1
J	.	.	.	.	4	1	1	1	14	11	9	4	43	3	10	5	21	4	4	1
K	.	.	.	.	4	3	1	1	16	14	6	2	43	8	6	3	21	6	3	1
L	.	.	.	.	2	3	1	1	17	12	6	3	43	9	7	2	9	6	3	1
M	.	.	.	.	2	2	2	2	25	20	13	2	43	14	16	3	12	9	6	1
N	.	.	.	.	7	5	3	1	35	25	16	2	43	15	17	3	16	10	9	2
O	.	.	.	.	4	11	1	1	26	23	19	3	43	17	21	3	13	7	5	1
P	.	.	.	.	4	3	2	1	28	23	19	3	43	29	18	3	12	7	5	1
R	.	.	.	.	5	3	1	1	15	9	5	1	30	22	16	4	11	7	5	1

Figure 2. - EPIC Tillage Erosion Rates.

Resource Soil Group 3

	PRACTICE											
	CM				CT				TR			
	TILLAGE				TILLAGE				TILLAGE			
	FLPW	SPLW	TILC	TILZ	FLPW	SPLW	TILC	TILZ	FLPW	SPLW	TILC	TILZ
	USLE	USLE	USLE	USLE	USLE	USLE	USLE	USLE	USLE	USLE	USLE	USLE
LRR												
A	14	11	7	2	7	6	4	2	5	4	2	1
B	3	2	2	1	3	3	3	2	1	1	1	1
C	5	5	4	2	3	3	2	1	2	2	2	1
D	4	3	3	2	1	1	1	1	1	1	1	1
E	2	2	1	1	1	1	1	1	1	1	1	1
F	2	1	1	1	1	1	1	1	1	1	1	1
G	3	3	3	2	2	2	2	1	2	2	1	1
H	4	4	3	2	2	2	2	1	2	2	2	1
I	7	6	5	2	3	3	3	1	3	3	2	1
J	7	6	5	2	3	3	3	1	3	3	2	1
K	8	7	3	2	5	4	2	1	5	5	2	1
L	11	8	4	2	6	4	2	1	5	4	2	3
M	21	16	11	2	11	8	6	1	10	8	5	1
N	21	15	9	2	11	7	5	1	12	8	5	1
O	26	21	18	3	13	11	8	1	12	10	8	1
P	22	17	14	2	10	8	7	1	9	7	6	1
R	11	6	4	1	6	4	2	1	6	4	2	1
S	35	19	11	2	17	9	5	1	18	10	6	1
T	22	19	13	4	11	9	7	2	15	12	8	3
U	25	20	15	3	23	9	8	2	11	9	7	2

Figure 3. EPIC erosion rates and acreage by Land Resource Region.

RESOURCE SOIL GROUP 3

	CROP GROUP									
	FAL		HAY		HRC		LRC		SNG	
	USLE	ACRES	USLE	ACRES	USLE	ACRES	USLE	ACRES	USLE	ACRES
LRR										
A	.	.	3	849	.	.	39	47	17	809
B	4	16420	1	2836	.	.	.	.	2	32921
C	15	64	4	886	.	.	12	14	5	852
D	4	756	1	808	1	80	1	6	3	2075
E	3	3121	1	4249	5	86	.	.	2	6806
F	2	42187	1	8324	4	4171	2	4481	1	70471
G	6	15334	1	9158	5	4708	6	900	2	23355
H	7	12929	1	5061	6	26262	2	39510	3	86517
I	.	.	1	550	7	4175	7	937	2	2257
J	.	.	1	717	11	2343	12	753	4	8373
K	.	.	3	4638	14	2439	12	368	6	1595
L	.	.	3	6367	12	8352	12	1542	6	2155
M	.	.	2	27156	20	64533	23	45211	9	25076
N	.	.	3	16627	25	6633	30	6807	10	3540
O	.	.	11	18	23	94	24	734	7	163
P	.	.	3	4745	23	6402	21	18514	7	4800
R	.	.	3	4868	9	4162	22	407	7	861
S	.	.	8	4471	26	5326	27	599	24	1172
T	.	.	5	79	19	657	22	554	9	130
U	.	.	2	12	.	.	24	60	.	.
TOTALS		90811		102419		162423		121464		273928

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Figure 4. - 1982 NRI Erosion Rates And Acreage By Land Resource Region

RESOURCE SOIL GROUP 3

	CROP GROUP									
	FAL		HAY		HRC		LRC		SNG	
	USLE	ACRES	USLE	ACRES	USLE	ACRES	USLE	ACRES	USLE	ACRES
LRR										
A	33	7	6	849	3	17	9	47	6	794
B	6	16420	1	2836	1	395	5	740	7	32921
C	3	64	1	671	1	58	6	44	3	852
D	4	920	0	1964	1	239	1	396	2	3289
E	1	3121	0	4249	7	86	1	73	1	6806
F	2	42187	1	8324	3	4172	3	4481	2	70471
G	2	15334	0	9158	3	4708	2	900	2	23355
H	2	13193	1	3061	4	26262	4	39510	2	86517
I	3	173	1	519	5	4175	5	937	3	2257
J	2	111	2	717	7	2343	9	753	5	8373
K	6	30	2	5120	5	2859	5	393	4	1699
L	13	11	3	6367	11	8332	10	1542	7	2155
M	17	164	4	27156	17	84533	20	45211	12	25076
N	.	.	2	16627	15	8633	18	6807	10	3540
O	5	25	2	18	16	94	9	756	13	163
P	13	223	1	4719	15	6402	17	18514	11	4800
R	3	12	1	4568	11	4162	11	407	6	861
S	14	20	2	4471	13	5326	15	599	9	1172
T	.	.	1	79	8	682	9	554	7	130
U	2	47	1	433	.	.	6	60	1	267
TOTALS		92062		104206		163498		122722		275518

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Figure 5. Erosion rates for conventional, 1982 NRI, and terraced.

ALL

	RESOURCE SOIL GROUP											
	2			3			4			8		
	EROSION			EROSION			EROSION			EROSION		
	CNV	NRI	TER	CNV	NRI	TER	CNV	NRI	TER	CNV	NRI	TER
	USLE	USLE	USLE	USLE	USLE	USLE	USLE	USLE	USLE	USLE	USLE	USLE
LRR												
A	2	4	1	11	6	2	17	3	4	29	16	.
B	2	4	1	2	6	1	7	8	2	24	11	1
C	3	1	1	5	2	2	37	9	15	81	20	3
D	1	0	1	3	2	1	4	2	2	14	2	5
E	1	1	1	2	1	1	2	1	1	16	2	1
F	2	2	1	1	2	1	3	3	1	8	7	2
G	2	2	1	3	2	1	4	3	1	10	5	3
H	3	2	1	4	3	2	9	4	3	22	8	10
I	2	4	1	6	4	2	8	4	2	23	4	9
J	3	5	2	6	5	1	10	7	7	86	8	10
K	3	2	1	7	3	2	12	7	4	12	9	3
L	3	5	1	8	7	2	20	11	5	33	13	9
M	5	7	2	16	15	5	42	22	17	94	30	40
N	6	6	2	15	9	5	35	12	15	66	16	33
O	6	7	.	21	10	8	27	31	.	2	71	.
P	7	8	2	17	14	6	44	21	14	81	37	32
R	4	3	2	6	6	2	13	5	4	20	8	1
S	3	5	2	19	9	6	17	11	5	24	18	8
T	11	5	4	19	8	8	52	16	57	17	24	1
U	5	1	.	20	1	7	.	1	.	.	22	.

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LONG TERM PRODUCTIVITY IMPACTS OF EROSION ON CROPLAND IN THE UNITED STATES

By Paul Dyke

As mentioned in earlier presentations, we started off with an EPIC generated data set of about 1.2 billion numbers and have been boiling it down to a more usable size. You know what happens when you continue to boil something--it's possible to end up with nothing. We're progressively moving down to a bottom line where everything is averaged to the point that I'm sure some people will conclude nothing is left. An earlier reference was made to splitters and lumpers. The material I'm going to present is massive lumping. As we present the data, I want to emphasize the material is aggregated across the entire United States. This analysis represents a reporting with most of the individual problems unaddressed. I so prefaced this presentation in order to alert everyone to the hidden danger of superficial conclusions.

Now, what did we do? We processed the EPIC data showing the impact of erosion on production and fertilizer use by calculating weighted indices according to the cropping patterns shown in the 1982 NRI. Crops were grouped into high residue row crops (corn and sorghums), low residue row crops (cotton, soybeans, peanuts, and sunflowers), small grains, hay, and fallow. These five groups were processed by each RCA group across all conservation practices. Now the questions was, "What erosion rates do we use to show projection?" The CARD model sets up many alternative rates to be addressed in the different scenarios. We were not, however, at this point ready to talk about these alternatives. We needed some realistic erosion rates to project for future years. Thus, the decision was made to use the erosion rates as reported in the 1982 NRI. In other words, we projected the 1982 cropping patterns and erosion rates using the EPIC coefficients for 100 years and then summarized by LRR's.

The results of the projected erosion productivity index (EPI) for the acreages in each land resource region are shown in Table 1. Let's look at the LRR M example. This region had 87 million acres of cropland that did not lose productivity in a hundred years. This includes both the non-eroding and eroding inventory bases, encompassing all Class 1, W's, S's, and C's without an erosion problem plus the E soils with erosion but not a loss of produc- tivity. (These tables are only water erosion tables; they do not include wind erosion.) The right column shows the thousands of acres out of the NRI falling into each land resource region. If we look at the bottom line of Table 1 we find an inventory of 420,387,000 acres of cropland. Of this total cropland, 85 percent did not show an erosion problem or did not erode within the projected hundred years to the extent that productivity would be lessened. It may have eroded, it may have caused offsite damages, it may have required additional amounts of fertilizer and lime; however, the productivity was not affected.

Table 1. 2080 EPI for all Cropland Eroding At 1982 NRI Rates in Thousands of Acres

Table of LRR by EPI

LRR / EPI FREQUENCY / PERCENT	:100	:95-95	:95-90	:90-85	:85-80	:UNDER 80:	TOTAL
A	1241 0.30	70 0.02	143 0.03	0 0.00	23 0.01	21 0.00	1498 0.36
B	12954 3.01	1210 0.29	984 0.23	0 0.00	0 0.00	473 0.11	15302 3.64
COE	22512 5.36	215 0.05	24 0.01	524 0.08	538 0.08	238 0.06	23651 5.63
F	47865 11.39	298 0.07	664 0.16	0 0.00	0 0.00	0 0.00	48827 11.61
G	18052 4.29	104 0.02	573 0.14	0 0.00	0 0.00	139 0.03	18867 4.49
H	64801 15.41	1436 0.34	26 0.01	0 0.00	0 0.00	231 0.05	66493 15.82
I	3535 0.85	46 0.01	0 0.00	6 0.00	0 0.00	13 0.00	3620 0.86
J	6668 1.59	3 0.00	92 0.02	73 0.02	0 0.00	0 0.00	6837 1.63
K	9503 2.26	187 0.04	21 0.00	0 0.00	0 0.00	0 0.00	9691 2.31
L	18576 4.42	311 0.07	1565 0.37	56 0.01	6 0.00	323 0.08	20836 4.96
M	87021 20.70	15859 3.77	8718 2.07	2007 0.48	616 0.15	250 0.06	114473 27.23
N	8718 2.07	4346 1.03	1954 0.46	988 0.24	67 0.02	1191 0.28	17305 4.12
OP	36222 8.62	5309 1.26	2884 0.69	1041 0.25	13 0.00	79 0.02	45547 10.83
R	1784 0.42	986 0.23	1294 0.31	948 0.23	102 0.02	697 0.17	5801 1.38
S	5099 1.20	719 0.17	2522 0.60	19 0.00	74 0.02	122 0.03	8505 2.02
TU	13083 3.11	62 0.01	4 0.00	0 0.00	1 0.00	2 0.00	13152 3.12
TOTAL	357293 84.95	31155 7.41	21438 5.10	5462 1.30	1260 0.30	3778 0.90	420387 100.00

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Let me re-emphasize at this point what we are reporting. We need to make a very clean distinction between productivity, which is a long-term impact, and production as it is recorded in annual yields. Productivity is the loss in the natural base; it's the permanent loss of potential production. What is not accounted for are losses due to soil sediments covering up crops, losses in the crop stand as the plants are washing out, losses caused by gully erosion due to increased cost in tillage operations, and land engulfed by gullies. These natural processes and other erosion related factors reduce the production or the yield. This analysis reports long-term productivity losses, not annual yield losses, and we need to keep this distinction in mind.

The EPI shown in Table 1 expresses productivity losses that could not be replaced by increasing the application of nitrogen, phosphorus, and lime. The 95-90 column shows 21 million acres or 5 percent of the cropland in the United States would lose 5 to 10 percent of its productivity within 100 years. In cells shown in Table 1, the top number is the acreage in thousands of acres. The bottom number is the percent of the United States cropland. In LRR M we see, for example, that 2 percent or 8.7 million acres lose between 5 and 10 percent of their productivity within an 100-year period. This erosion crates an irreversible loss of productivity that cannot be offset by fertilizer additions. Such a loss is permanent due to a reduction in water holding capacity, root penetration, or similar factors restricting plant growth.

Table 2 shows the increased nitrogen requirements associated with erosion. This index goes up rather than down. This additional nitrogen is required to replace the amounts lost in runoff and sediment. The fifth column shows the acres of cropland that need a 20 to 30 percent increase over non-eroding nitrogen requirements in order to maintain the productivity levels as shown on the EPI indicies of Table 1. This additional nitrogen is expressed as a percentage increase per unit of production. For example, if one uses the old rule of thumb of a pound of nitrogen per bushel of corn, a 30 percent increase would require 1.3 pounds of nitrogen per bushel of corn. As an interesting tangent, we checked EPIC against this rule of thumb and found it came out very close in the non-eroding conditions. This increase in nitrogen per bushel may assume the form of a constant amount of nutrients with a reduced yield. For example, one might apply 200 pounds of nitrogen and in the non-eroding case harvest 200 bushels of corn while in the eroding case glean only 170 bushels of corn.

A comment on methodology is appropriate at this time dealing with an assumption about nitrogen. An earlier presentation showed the organic carbon content with soil starting from its virgin state (the breaking out of the native sod). In the early stages organic carbons can be mined. These carbons will substitute for nitrogen fertilizer. In the EPIC runs used for the RCA we assumed that the cropland had been in production for 100 years. What did that do? It drove the organic carbon curve to a low level where nitrogen remained stable. No benefits were derived from exploiting the nitrogen base. This 100 years of cropping is reasonable for most croplands. Such an assumption has given us a "put and take" situation. The nitrogen use reported is that which is actually being removed by harvesting crops or eroding soils. Crop nitrogen is not supplemented by a deterioration through time or mining of these organic carbons.

Indices for phosphorus are shown in Table 3. As was discussed in an earlier presentation, phosphorus is attached to the soil particles. When erosion occurs, some soils require very large amounts of supplemental phosphorus to bring the soil back into equilibrium and maintain productivity.

The changes in lime requirements are given in Table 4. This liming was required either to compensate for the changing pH due to nitrogen applications or to correct for the aluminum toxicities and other problems as the soil eroded. When the pH became unbalanced the lime was applied. As one can see, 6 percent of all soils required an increase in lime above 140 percent of their non-eroding levels. The conclusion, therefore, is that as erosion occurs significant increases in lime must be used to correct for the changes in soil conditions.

Table 2. 2080 Nitrogen Index for all Cropland Eroding at 1982 NRI Rates in Thousands of Acres

Table of LRR by Nitrogen Index

LRR	NITROGEN INDEX							
FREQUENCY / PERCENT	100-101	101-105	105-110	110-120	120-130	130-140	OVER 140	TOTAL
A	1026	2	333	34	29	11	0	1498
	0.26	0.00	0.08	0.01	0.01	0.00	0.00	0.36
B	5595	7215	1026	296	964	0	205	15302
	1.33	1.72	0.24	0.07	0.23	0.00	0.05	3.64
CDE	19905	2981	173	553	3	59	0	23651
	4.73	0.70	0.04	0.13	0.00	0.01	0.00	5.63
F	17729	25133	5964	0	0	0	0	48827
	4.22	5.98	1.42	0.00	0.00	0.00	0.00	11.61
G	4554	12624	1149	259	41	0	0	18868
	1.08	3.05	0.28	0.06	0.01	0.00	0.00	4.49
H	37679	25862	2613	340	0	0	0	66493
	8.96	6.15	0.62	0.08	0.00	0.00	0.00	15.82
I	2391	1229	0	0	0	0	0	3620
	0.57	0.29	0.00	0.00	0.00	0.00	0.00	0.86
J	2379	4176	282	0	0	0	0	6837
	0.57	0.99	0.07	0.00	0.00	0.00	0.00	1.63
K	5763	3783	124	0	21	0	0	9691
	1.37	0.90	0.03	0.00	0.00	0.00	0.00	2.31
L	12590	6782	1148	299	6	0	0	20826
	2.99	1.61	0.28	0.07	0.00	0.00	0.00	4.96
M	59131	31303	12009	10303	1567	160	0	114473
	14.07	7.45	2.86	2.45	0.37	0.04	0.00	27.23
N	5970	7486	2756	1102	0	0	0	17305
	1.42	1.78	0.66	0.26	0.00	0.00	0.00	4.12
OP	29234	10517	4858	956	370	0	13	45547
	6.95	2.50	1.06	0.23	0.09	0.00	0.00	10.83
R	4320	0	1319	161	0	0	0	5801
	0.55	0.00	0.79	0.04	0.00	0.00	0.00	1.38
S	4252	3105	840	308	0	0	0	8505
	1.01	0.74	0.20	0.07	0.00	0.00	0.00	2.02
TU	12162	925	20	4	0	0	0	13132
	2.90	0.22	0.00	0.00	0.00	0.00	0.00	3.12
TOTAL	222752	143283	36306	19604	2996	229	218	420387
	52.99	34.08	8.64	3.47	0.71	0.05	0.05	100.00

Table 5 shows the soils and the breakdown of the categories we deem significant. We have little confidence in values between 99 and 95 percent. However, we believe values below 95 percent represent significant change. We deleted from Table 1 all of the soils that did not have at least 5 percent permanent loss in productivity over 100 years. These remaining acreages were then distributed so that we could get some "feel" for where the problems do, in fact, exist. This table reveals 32 million acres in the United States lose more than 5 percent of their productive capacity in 100 years at 1982 erosion rates. Closer inspection indicates that LRR M contains 36 percent of the total problem area. But let me repeat. These acres are not intended to represent all acres with erosion problems. They are acres with a potential productivity problem due to erosion.

The bottom line is this. We have boiled 1.2 billion numbers down and projected them through the year 2080. These tables show the acreages by land resource regions and the respective EPI, nitrogen, phosphorus, and lime indices. When we project for a 100-year period using 1982 cropping patterns and water erosion rates, the loss in productivity and increase in fertilizer due to erosion are distributed as shown. now, how do I interpret this? One can read it in one of three ways. One can say, "No permanent problem exists if we are willing to pay the cost of replacing the nutrients lost due to erosion." The second alternative is, "Our models aren't good enough to detect the non-correctable problems." Or the third interpretation, which I believe is the correct one, is, "The NRI data reflect all conservation practices that have been installed and are in place in the United States today."

These include all the SCS technical assistance programs, ASCS payments, and loan programs for soil conservation. Given the erosion control practice that have been installed and are being maintained and the conservation education that has occurred and is taking place, we are doing an acceptable job of preserving our soil resources." The NRI includes the erosion rates from all the terraces, conservation practices, and everything that was on the land in 1982. Now to support this hypothesis, if one looks at the average erosion rate from the NRI, it is 4.4 tons per acre on 421 million acres of cropland. I'm not sure what the average weighted T is across the United States, but if you assumed it to be 5 or even 4 tons per acres, then 4.4 tons is close to the acceptable level.

The other question for which we need an answer is, "What would the land base and erosion rates be if the programs were not in place?" This must be answered before one can say how good a job we are doing So what I've done is present half of the story. This is where we are. The missing question is, "Where would we be without the conservation programs?" I think there are techniques which can be used to answer the second question. That is the next step in our analysis.

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Table 3. 2080 Phosphorus Index for all Cropland Eroding at 1982 NRI Rates in Thousands of Acres.

Table of LRR by Phosphorus Index

LRR	PHOSPHORUS INDEX						
FREQUENCY / PERCENT	100-101	101-105	105-110	110-120	120-130	130-140	OVER 140	TOTAL
A	1096 0.26	146 0.03	176 0.04	35 0.01	6 0.00	0 0.00	46 0.01	1498 0.36
B	9055 2.15	3753 0.89	268 0.06	891 0.21	35 0.02	279 0.07	984 0.23	15302 3.64
CDE	20821 4.81	1715 0.41	1258 0.29	152 0.04	255 0.06	0 0.00	0 0.00	23651 5.63
F	17729 4.22	23869 5.54	6860 1.63	352 0.08	35 0.01	582 0.14	0 0.00	48827 11.61
G	4984 1.08	13632 3.08	604 0.14	875 0.21	0 0.00	223 0.05	0 0.00	18868 4.49
H	28677 6.59	35744 8.50	2916 0.69	957 0.23	0 0.00	0 0.00	0 0.00	66493 15.82
I	4958 0.78	662 0.16	0 0.00	0 0.00	0 0.00	0 0.00	0 0.00	3620 0.86
J	2972 0.71	3841 0.87	225 0.05	0 0.00	0 0.00	0 0.00	0 0.00	6837 1.63
K	5402 1.29	3099 0.73	1190 0.29	21 0.00	0 0.00	0 0.00	0 0.00	9691 2.31
L	12999 2.97	1139 0.27	2717 0.65	4123 0.98	366 0.09	2 0.00	0 0.00	20836 4.96
M	58131 14.07	712 0.17	11359 2.70	25445 6.10	9750 2.32	2810 0.68	5688 1.35	114473 27.23
N	5950 1.42	2361 0.56	3123 0.74	4364 1.01	1099 0.25	397 0.13	0 0.00	17305 4.12
OP	29234 6.95	28 0.01	1668 0.25	10219 2.43	2887 0.68	669 0.16	799 0.19	45547 10.83
R	2320 0.55	0 0.00	1284 0.31	2162 0.51	36 0.01	0 0.00	0 0.00	5801 1.38
S	4897 1.09	548 0.13	2971 0.59	960 0.23	327 0.08	0 0.00	0 0.00	8505 2.02
TU	12110 2.88	75 0.02	870 0.21	58 0.01	8 0.00	7 0.00	4 0.00	13132 3.12
TOTAL	216317 51.46	89477 21.28	36361 8.64	50703 12.06	15591 3.71	4507 1.07	7452 1.77	420388 100.00

Table 4. 2080 Lime Index for All Cropland Eroding at 1982 NRI Rates in Thousands of Acres

Table of LRR by Lime Index

LRR	LIME INDEX						
FREQUENCY / PERCENT	100-101	101-105	105-110	110-120	120-130	130-140	OVER 140	TOTAL
A	1096 0.26	167 0.04	149 0.04	80 0.02	0 0.00	0 0.00	6 0.00	1498 0.36
B	8756 1.61	5780 1.38	1328 0.32	268 0.06	1169 0.28	0 0.00	0 0.00	15302 3.64
CDE	20838 4.96	2371 0.56	351 0.08	63 0.01	31 0.01	0 0.00	0 0.00	23651 5.63
F	20939 4.98	20827 4.95	6960 1.66	101 0.02	0 0.00	0 0.00	0 0.00	48827 11.61
G	5114 1.22	9896 2.35	2663 0.63	620 0.15	575 0.14	0 0.00	0 0.00	18868 4.49
H	25151 6.01	10814 2.57	9579 2.28	4608 1.10	7423 1.77	4827 1.15	3991 0.95	66493 15.82
I	2340 0.56	30 0.01	722 0.17	521 0.12	0 0.00	0 0.00	0 0.00	3620 0.86
J	2541 0.60	315 0.07	803 0.19	2917 0.57	762 0.18	0 0.00	0 0.00	6837 1.63
K	5360 1.27	1163 0.28	2205 0.52	818 0.19	124 0.03	0 0.00	21 0.00	9691 2.31
L	12499 2.97	946 0.23	2884 0.69	2312 0.55	1629 0.39	176 0.04	389 0.09	20836 4.96
M	59131 14.07	2687 0.64	19373 4.61	4752 1.13	9477 2.25	7094 1.69	11959 2.84	114473 27.23
N	11906 2.71	219 0.05	623 0.15	648 0.15	116 0.03	530 0.13	3768 0.90	17305 4.12
OP	38983 9.27	14 0.00	49 0.01	352 0.08	1464 0.35	411 0.10	4275 1.02	45547 10.83
R	2323 0.55	0 0.00	0 0.00	2252 0.53	480 0.11	33 0.01	736 0.17	5801 1.38
S	4171 0.99	183 0.04	268 0.06	2379 0.57	1260 0.30	0 0.00	244 0.06	8503 2.02
TU	12904 3.05	159 0.04	128 0.03	22 0.01	8 0.00	7 0.00	4 0.00	13132 3.12
TOTAL	231545 55.08	55579 13.22	48085 11.44	22188 5.28	24518 5.83	13279 3.11	25394 6.04	420387 100.00

Question: Do these projections include improvements in technology?

P. Dyke: No, 1982 technology is assumed.

Question: Is it possible that the conservation practices are not installed on those soils that need them most?

P. Dyke: I think that may be, and that's where we really need to spend some time trying to analyze our data. The other thing we must remember is that this analysis was applied to the cropland base itself. Most of these RCA 8 soils, the highly eroding soils, are in range or other non-cropland uses. They're not included in this analysis.

Question: In the attempt to offset productivity losses with additional fertilizer, are we adding more nutrients to the streams?

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Table 5: 2080 EPI for all Cropland Eroding at 1982 NRI Rates in Thousands of Acres

Table of LRR by EPI

LRR / EPI FREQUENCY PERCENT	95-90	90-85	85-80	UNDER 80	TOTAL
A	143 0.45	0 0.00	23 0.07	21 0.06	187 0.59
B	964 3.02	0 0.00	0 0.00	473 1.48	1437 4.50
CDE	24 0.08	324 1.01	338 1.06	238 0.75	924 2.89
F	664 2.08	0 0.00	0 0.00	0 0.00	664 2.08
G	573 1.79	0 0.00	0 0.00	139 0.43	712 2.23
H	26 0.08	0 0.00	0 0.00	231 0.72	257 0.80
I	0 0.00	6 0.02	0 0.00	13 0.04	19 0.06
J	93 0.29	73 0.23	0 0.00	0 0.00	166 0.52
K	21 0.06	0 0.00	0 0.00	0 0.00	21 0.06
L	1565 4.90	56 0.18	6 0.02	323 1.01	1950 6.10
M	8718 27.30	2007 6.28	616 1.93	250 0.78	11592 36.29
N	1954 6.12	988 3.09	87 0.27	1191 3.73	4219 13.21
OP	2884 9.03	1041 3.26	13 0.04	79 0.25	4017 12.58
R	1284 4.02	948 2.97	102 0.32	697 2.18	3031 9.49
S	2522 7.90	19 0.06	74 0.23	122 0.38	2736 8.57
TU	4 0.01	0 0.00	1 0.00	2 0.01	7 0.02
TOTAL	21438 67.12	5462 17.10	1260 3.95	3778 11.83	31939 100.00

P. Dyke: Most likely we are. The added nitrogen load on the streams would be one of the externality costs we have not included. This analysis reported onsite damages and long-term productivity losses only. That's why it is critical we remember the limitations as we talk about these numbers. I think it's useful to present them, but they must be taken within the light and limitations of the analysis.

Question: Did the year-to-year variation in crop yields stay about equal despite the erosion of topsoil?

P. Dyke: The mean yields may have dropped slightly, but the frequency of crop failure definitely increased. The standard deviations got much larger as the eroding soil interacted with the weather. To look at the mean itself is misrepresenting the destabilizing effect in the agricultural community. The problems associated with this increased variability have not been addressed yet.

Question: Do you have this information available?

P. Dyke: I think this type of analysis should be done and would provide a lot of information about the destabilizing effects of erosion. The information is available in the EPIC data base. I've never pulled it out and summarized it. We did look at it on a superficial level. That is why I could answer the question. Yes, the variation did increase. How much? I can't tell you.

Question: Given the variation between the types of soils, the rotations, and the cropping practices, is there not a tremendous variation in the results coming from the EPIC output?

P. Dyke: Yes, there is tremendous variation in the output just as there is in nature. This is the problem in summarizing the analysis to this level of aggregation. One can say very little about the specific problem soils by looking at these summary numbers. That's where we have to back up and begin analyzing the individual problems. We all know we can show examples where there are tremendous problems in erosion on specific soils. And that brings us back to the reason for developing and maintaining detailed analytical tools such as EPIC. This allows us to identify, study, and "target" the problem areas.

1982 NATIONAL RESOURCES INVENTORY DATA ON EROSION BY MAJOR LAND RESOURCE AREA

By Tommy George

Introduction

The 1982 National Resources Inventory (NRI) was authorized by the Rural Development Act 1972 and Soil and Water Resources Conservation Act of 1977. It is the only federal inventory that maintains current comprehensive data on the status and conditions of America's nonfederal soil, water, and related resources.

The NRI presents basic statistics, not data analyses. They are estimates, not absolute values. The estimates were obtained through a careful sampling of the resource universe in which the major data elements were observed, classified, and recorded.

The NRI was designed for statistical reliability at the major land resource area (MLRA) level.[2/] While it was generally too expensive to sample MLRA's of much less than 1 million acres at a rate sufficient to meet NRI standards, this should only minimally affect the usefulness of NRI data. SCS staffs usually combine these small areas with similar adjacent MLRA's within the state when analyzing resources and related problems.

The 1982 NRI data can be used at several levels of detail. Examples are given in this paper for sheet and rill erosion at the national, regional, state, and MLRA levels.

Erosion on Cropland

Nationally, the 1982 NRI estimated average annual sheet and rill erosion at 4.4 tons per acre on 421 million acres of cropland (Table 1). National averages may, over time and from one inventory to another, indicate whether general progress is being made in erosion control. They do not, however, tell us where most erosion occurs, which areas have the highest erosion rates, or what is the relative significance of the problem from place to place.

Land resource regions (LRR's) consist of geographically grouped MLRA's and are another context for analyzing NRI data (Figure 1). For example, in LRR M, the Central Feed Grains and Livestock Region or Corn Belt, 115 million acres of cropland have average annual sheet and rill erosion of 7.1 tons per acre.

Table 1.--Cropland sheet and rill erosion for selected data contexts, 1982

Data context	Cropland area	Average annual erosion
	million acres	tons/acre
United States	421	4.4
Land resource region M	115	7.1
Iowa (in LRR M)	26	9.4
Missouri (in LRR M)	11	11.8
MLRA 107 (in LRR M)[1/]	9	13.8

1/ In MLRA 107, 8.8 million of the 9 million acres of cropland are cultivated cropland with average annual erosion of 14.1 tons/acre.

LRR M contains a fourth of our cropland; its average rate of sheet and rill erosion is 60 percent higher than the national average.

By observing state averages, one can begin to zero in on erosion problems. Iowa, located entirely within LRR M, has average annual sheet and rill erosion of 9.4 tons per acre on its 26 million acres of cropland. This rate is more than twice the national average (Table 1).

By looking at MLRA's, we can see the variation of erosion rates within a state (Figure 2). Among Iowa's seven MLRA's, sheet and rill erosion on cropland ranges from 4.7 tons per acre (MLRA 103) to 13.6 tons per acre (MLRA 107) (Table 2).

This type of information has been used as one basis for focusing erosion control efforts on acres with the most severe erosion.

Erosion on Rangeland

The estimated average annual sheet and rill erosion on rangeland in Colorado is 2.6 tons per acre. MLRA data for Colorado indicate where this erosion is most severe (Figure 3 and Table 3).

Table 2.--Estimated average annual erosion on all Iowa cropland, by MLRA, 1982.

MLRA	Sheet and rill erosion		Cropland area
	1,000 tons	tons/acre	1,000 acres
102B	1,519.7	7.0	216.2
103	31,425.5	4.7	6,629.2
104	20,096.5	5.8	3,468.8
105	20,176.9	13.0	1,553.9
107	82,480.8	13.6	6,073.9
108	69,346.0	10.7	6,460.7
109	22,746.0	11.2	2,038.0
TOTAL	247,791.8	9.4	26,440.7

Because of their small acreages, some MLRA's were combined with adjacent ones to obtain more reliable data. For example, NRI data for 414,000 acres in MLRA 35, 230,000 acres in MLRA 37, and 377,000 acres in MLRA 39 were combined. For the same reason, data from MLRA 47 was combined with 48A, 69 with 70, and 77 with 67.

Of all MLRA's in Colorado, including these combinations, MLRA 49 has the worst sheet and rill erosion problem on rangeland; on 1.6 million acres, average annual erosion is 8.1 million tons or 5.1 tons per acre--double the state average (Table 3).

Erosion on Forest Land

In 1982, average annual sheet and rill erosion on the 3.4 million acres of forest land in Illinois was estimated at 12.7 million tons or 3.7 tons per acre. But two-thirds of this erosion is on the 638,000 acres of grazed forest land (Table 4).

Grazed forest land in the state is eroding at an average annual rate of 8.3 million tons or 13.1 tons per acre. By MLRA, the annual rates range from 2.7 tons per acre (MLRA 95B) to 18.7 tons per acre (MLRA 115) (Figure 4 and Table 4).

The acreages of grazed forest land in Illinois MLRA's are very small, ranging from 8,000 to 300,000 acres. Data from an individual MLRA may not be significant, but the data become more reliable when the small areas are combined.

Table 3.--Estimated average annual erosion on Colorado rangeland, by MLRA, 1982.

MLRA	Sheet and rill erosion		Cropland area
	1,000 tons	tons/acre	1,000 acres
34	4,417.5	3.3	1,353.7
35,37,39	3,425.1	3.3	1,020.6
47,48A	11,313.7	3.2	3,535.9
48B	1,392.8	1.4	979.2
69	8,089.5	5.1	1,576.6
51	245.5	0.2	1,050.8
67,77	6,539.6	1.1	6,042.6
69,70	23,778.2	3.4	6,976.3
72	4,291.0	2.5	1,687.3
TOTAL	53,492.9	2.6	24,222.5

A much greater sampling intensity would have been required to make such small universes yield statistically reliable data. Other information may be needed to evaluate local problems of erosion on forest land, such as soil maps, farm plans, and forest management plans.

Figure 1. Land Resource Region "M". Central Feed Grain and Livestock Retion (Corn Belt)

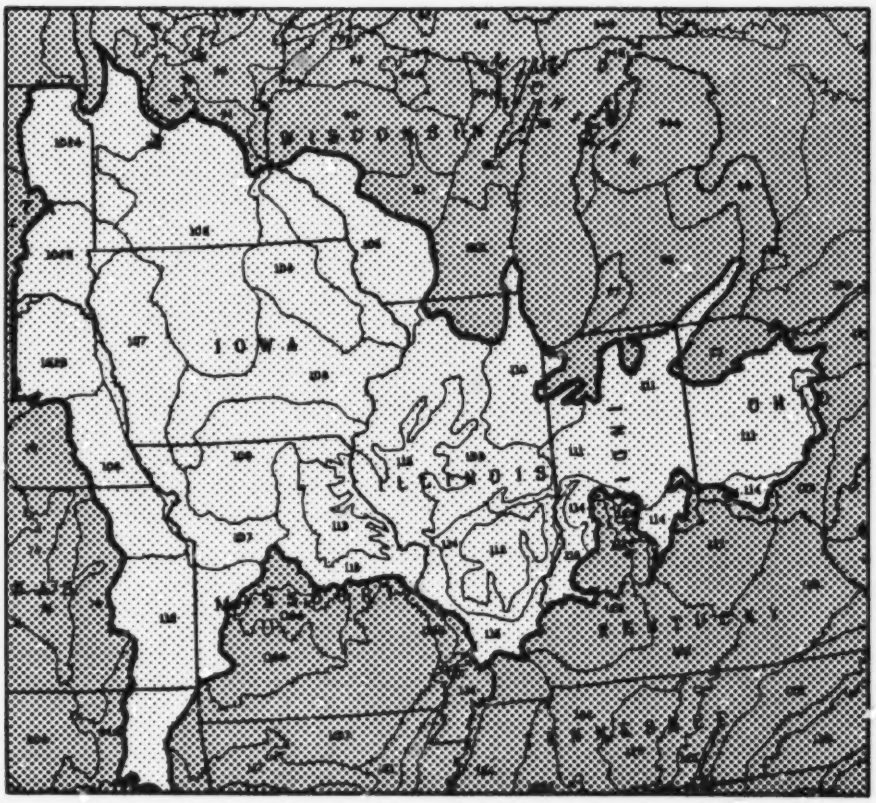

Figure 2. Estimated average annual sheet and rill erosion on all cropland 1982 NRI (MLRA)

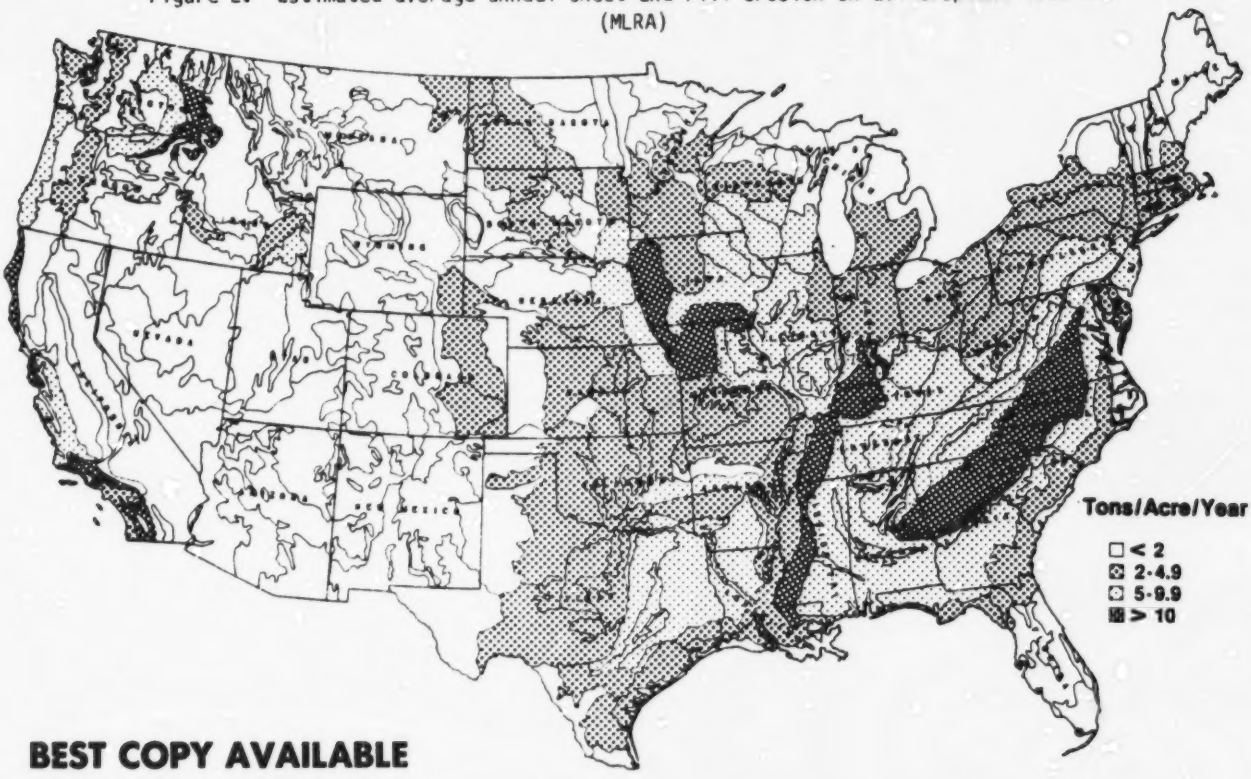

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Figure 3. Estimated average annual sheet and rill erosion on rangeland 1982 NRI (MLRA)

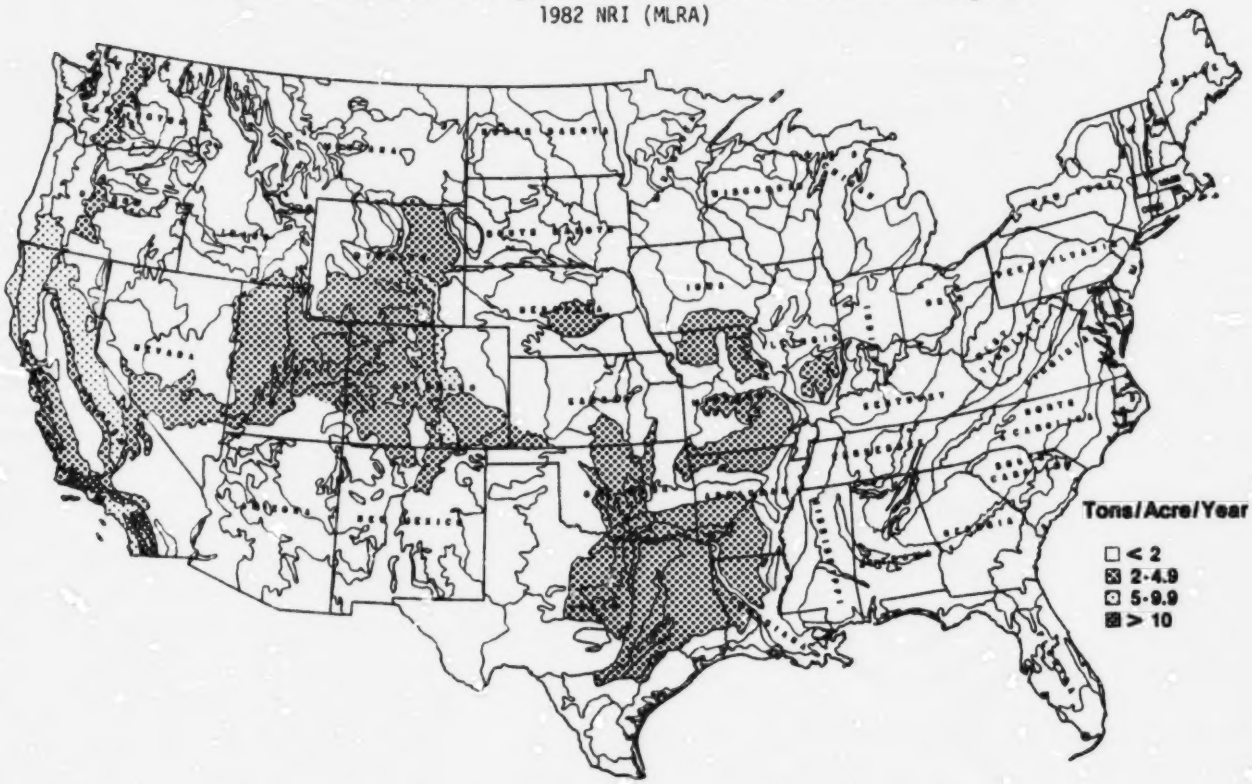

Figure 4. Estimated average annual sheet and rill erosion on grazed forest land 1982 NRI (MLRA)

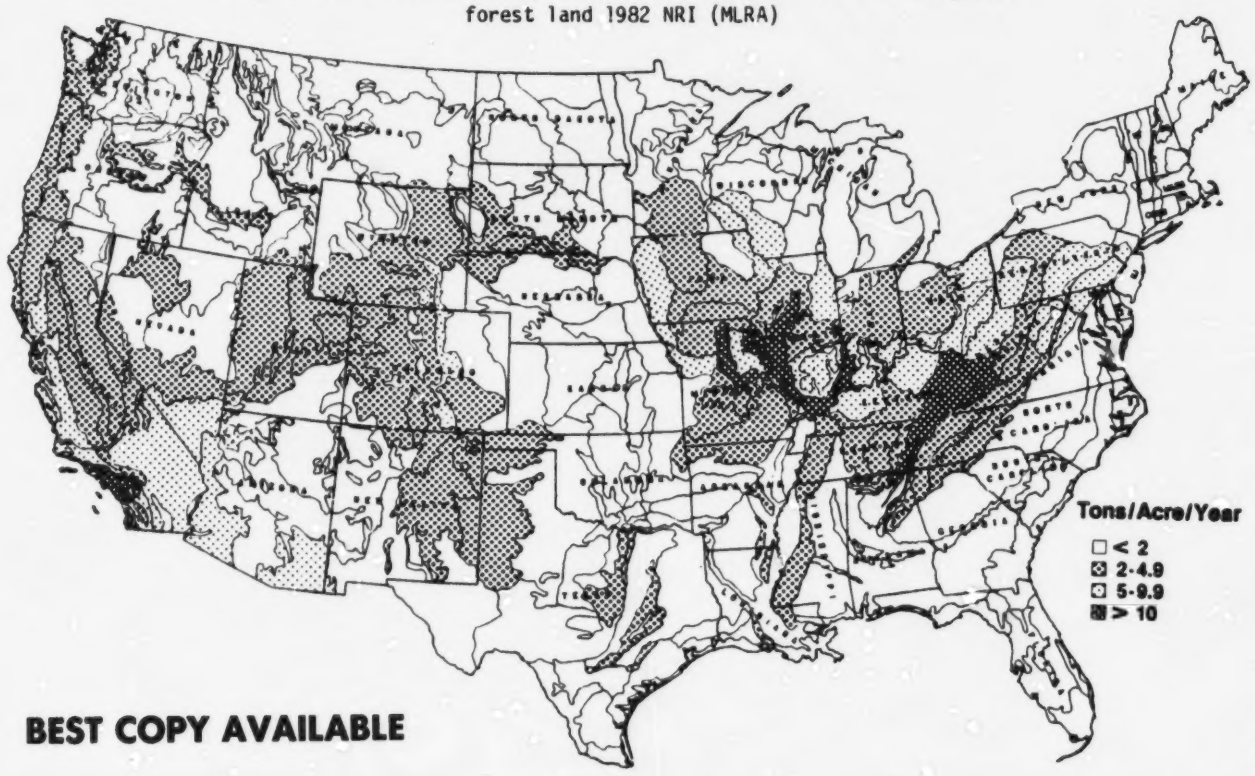

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Table 4.--Estimated average annual erosion on Illinois grazed forest land, by MLRA, 1982.

MLRA	Sheet and rill erosion		Cropland area
	1,000 tons	tons/acre	1,000 acres
95B	56.0	2.7	20.9
105	779.1	15.6	49.9
108	858.7	6.5	133.2
110	44.4	5.7	7.8
111	63.9	7.3	8.7
113	419.1	10.4	40.5
114	462.2	6.1	75.3
115	6,542.3	18.7	301.8
TOTAL	8,325.7	13.1	638.1

Summary

Erosion estimates on a national scale over a period of time give us only very general information on trends. Erosion data at the LRR and state levels begin to reveal broad areas with the worst erosion problems. Examination of data at more localized levels, such as MLRA portions of states, allows us to sharpen the focus on specific problem areas.

A similar approach can be used in analyzing NRI data for other land uses and for wind erosion and other conservation problems.

THE STRUCTURE, USE, AND LIMITATIONS OF THE 1980 RCA YIELD/SOIL LOSS SIMULATOR

By Paul Dyke

Introduction

The RCA yield/soil loss simulator was created as part of the Resource Conservation Act's (RCA) effort to study the impact of erosion on crop yields. The model was developed using nationally available data and was integrated into the structure of the National Agricultural Linear Programming (LP) Model at Iowa Statue University. This LP model was in turn used to provide long term resource analysis for the 1980 RCA report to Congress. The yield/soil loss simulator was designed to quantify the relationship between soil depth and crop yields. An understanding of this relationship is necessary in order to determine the impact of erosion (i.e., soil loss) on the inherent long-term productivity of our land resources. Many factors influence this relationship. Such things as climate, soil texture, slop, irrigation, and soil tilth will each alter the importance of soil depth. The simulator attempted to take these important factors into consideration when determining the influence of erosion on our ability to produce food and fiber.

Methodology and Data

Multiple regression techniques were used to estimate the equations for the 18 Water Resource Regions (WWR) as defined by the Water resources Council. Dummy variables were used to adjust for differences in the producing areas within each WWR. The equation formulated as follows:

Yield = f(Depth, Slope, Texture, Capability Subclass, Irrigation, Producing Area).

Yield. Data was taken from the ERS Normalized Yield files which represent an average yield for each crop at the 1974 technology level. Yields from 1100 SCS County Soil Surveys (collected 1960-1978) were normalized (using Soil Mapping Unit acreages as weights) to 1974 crop yields estimated from 8 years of SRS county historical crop yield data. This procedure effectively removes technological change from the data. This data base contained about 450,000 individual observations of unique soil mapping unit/crop combinations.

Depth. Depths, actually thicknesses, of three layers were obtained from SCS Soils-5 Data: (1) A-horizon, (2) B-horizon, and (3) depth from B to bedrock. Topsoil depths are reported in the uneroded phase. The topsoil depths were adjusted by erosion phase from the published Soil Surveys as follows:

If:	The depth is adjusted to:
Slightly (1-25% of topsoil is) eroded	87.5% of A-horizon depth
Moderately (25-75% of topsoil is) eroded	50.0% of A-horizon depth
Severely (75-100% of topsoil is) eroded	12.5% of A-horizon depth

Slope. Data were taken from the SCS Soil Surveys.

Texture. Data were taken from the SCS Soil Surveys. Four textures (loam, silt, clay, and sand) were included.

Capability Subclass. Data on the limiting factor (e, w, s, or c) were obtained from the SCS Soil surveys.

Irrigation. Data were taken from the SCS Soil Surveys. Yields were calculated for both irrigated and dryland.

Producing Area. The regression equations were developed by 18 water resource regions with correction coefficients internal to each equation to reflect the geographic and climatic variations among the producing areas within one region. This grouping was necessary in order to obtain sufficient numbers of observations for the statistical analysis.

Mean Values for the Independent Variable. Weighted average values for each independent variable (depth, slope, texture, and capability subclass) were calculated for each unique combination of crop, land group, and producing area. The 1977 NRI acre values were used to provide weights. These average values are necessary to drive the equations in the yield/soil loss simulators and are used in connection with changing soil depth to create projected yields.

Construction and Use of the Simulator

Once the statistical analyses were carried out, specific equations were analyzed, selected, and programmed into the yield/soil loss simulator to calculate current base yields. The simulator has the ability to estimate the impact on irrigated and non-irrigated yields of changing soil depth for soils of varying soil slopes, textures, and limiting conditions within the crop by producing area. Topsoil depth was utilized rather than erosion to create flexibility in the model USLE was used to determine an erosion rate for a specific crop rotation and practice. Given an erosion rate, topsoil depth was decreased accordingly, and another simulation was made to estimate yields at some future time, for example 2030.

Erosion rates from the 1977 National Resource Inventory were used with the model to provide data independent of the L.P. runs. These erosion rates were extrapolated over 50- and 100-year periods to estimate the change in yields that would occur if current erosion rates continued unabated. In many producing areas, the decrease in yield was as high as 30-40 percent on some land capability class-subclasses (III-e, IV-e and VI-e). However, these results need very careful interpretation because in some of these regions topsoil disappears in 10 to 20 years. The model does not fully incorporate all of the changes that occur when topsoil disappears. For instance, textures of the B-horizon are not in the model. This discontinuity limits projections of the model and requires caution when interpreting results. An alternative analytical procedure is to remove one inch of topsoil at a time to see the incremental impacts on yields. This method has the theoretical advantage of removing the time element from the analysis.

Results and Limitations

Depth

As the depth of the topsoil decreases, the effect on yield becomes increasingly greater.

As topsoil erodes, the B horizon becomes more important. The model adjusts for this factor and is often significant. In some regions, 10 to 12 percent of the observations revealed topsoil depths of less than 2 inches by the end of 100 years.

The third layer was often more statistically significant than the second, indicating the importance of water storage capacity. If a root restricting layer exists, the C horizon will likely be thin.

Slope

The slope generally had a significantly negative effect on yield.

In regions with predominantly W soils, the coefficient was sometimes positive, indicating drainage problems were more important than erosion.

In other producing areas the Soil Survey Data does not quantify steep slopes; rather, slopes are merely reported as "very steep," "rolling," "hilly," etc. For this reason, many observations had to be discarded which had the effect of lowering the average slope value in precisely those regions with steepest slopes. This occurred, for example, in the Northwest.

Texture

Deep sand soils, generally in association with Subclass S, often made yields increase. This was evident in southern regions where, in some cases, 70 to 80 percent of all observations had only sand or sand loam textures, with no clay or silt in the A horizon.

The model did not include textures from any horizon other than topsoil, and it has suffered criticism for this reason. The data were available from Soils-5 but were not used in the regressions.

Capability Subclass

The regression coefficients on the subclass variables gave mixed results but in general were of the direction and magnitude we expected. Erodable soils (E) generally showed results comparable to other studies with a decline in productivity due to erosion. S-type soils generally showed strong negative coefficients, indicating a significantly lower yield than E and W soils. Wet soils (W) with drainage problems often masked erosion in the soil groups 2 and 5 since these groupings included all subclasses. The coefficients on C-type soils were generally insignificant frequently due to the limited number of observations.

Some classification problems exist with capability class/subclass. As soils become severely eroded, the class may change from III-E to IV-E, or IV-E to VI-E. Soil series names may also change.

ISU soil group (1 to 5) combine II-E with S, W, and C soils and combine VI-E with VI-S, W, C, VII, VIII thereby making it difficult to isolate effects of erosion on II-E and VI-E soils. In some regions where W or S is predominant, interpretation f eroding soils is subject to error.

Producing Areas

In some regions, especially in the Southwest where the number of observations were low, differences between producing areas were insignificant. In some areas, however, differences were substantial.

Output

Examples of information generated by the simulator are shown in Table 1. The impacts of erosion on corn in producing area 35 (a part of Indiana) are shown in the top half of the table. The assumed erosion rates and beginning topsoil depths for each land group are also shown in the bottom half of the table. The data shown in the table are available for all of the RCA crops, producing areas, and soil groups.

The yield/soil loss simulator was the first attempt to quantify the impact of erosion on crop yield nationwide. We learned a great deal from the experience, which is continuing to help us search for better answers to the proper use and care of our natural resources.

Table 1. - Sample of Output from the 1980 RCA Yield/Soil Loss Simulator

Corn
Producing Area 35

Expected changes in yields of selected crops if 1977 erosion rates continue.

Soil Group 1/	1977 rate of water erosion (Tons/acre/year) 2/	Present yield (Bushel/acre)	--Percentage of Present Yield if erosion rate continues in-- 10 years	20 years	30 years	40 years	50 years
			--Percent--				
1	3.942	104.81	99.8	99.6	99.4	99.2	99.0
2	4.124	87.14	99.6	99.2	98.7	98.2	97.8
3	13.203	75.54	98.0	95.8	93.1	89.8	85.6
4	25.373	65.77	92.8	80.4	61.7	--	--
5	42.361	61.43	84.4	56.5	--	--	--

Impacts of erosion on yield.

Soil Group	1977 rate of water erosion (Inches/acre/year)	Topsoil Depth (Inches)	Years to erode topsoil at current rate	Present yield (Bushel/acre)	Present yield as percentage of soil Group 1	Yield reduction in 50 years or until topsoil disappears
1	.026	11.566	764	104.81	100.0	1.04 bu.
2	.027	9.688	255	87.14	83.1	1.92 bu.
3	.088	6.260	69	75.54	72.1	10.83 bu.
4	.169	4.136	24	65.77	62.8	25.19 bu.
5	.282	4.272	15	61.43	58.6	26.70 bu.

Soybeans
Producing Area 41

Expected changes in yields of selected crops if 1977 erosion rates continue.

Soil Group	1977 rate of water erosion (Tons/acre/year)	Present yield (Bushel/acre)	--Percentage of Present Yield if erosion rate continues in-- 10 years	20 years	30 years	40 years	50 years
1	3.17	34.38	99.9	99.9	99.8	99.8	99.7
2	4.95	28.90	99.7	99.4	99.1	98.8	98.4
3	16.57	26.24	98.0	95.6	92.7	89.3	84.8
4	18.08	22.94	96.0	90.9	83.8	71.0	59.2
5	32.24	20.24	98.5	96.2	93.0	88.1	79.7

Impacts of erosion on yield.

Soil Group	1977 rate of water erosion (Inches/acre/year)	Topsoil Depth (Inches)	Years to erode topsoil at current rate	Present yield (Bushel/acre)	Present yield as percentage of soil Group 1	Yield reduction in 50 years or until topsoil disappears
1	.021	16.81	794	34.38	100.0	0.00 bu.
2	.033	13.14	398	28.90	84.1	0.46 bu.
3	.110	7.83	71	26.24	76.3	3.99 bu.
4	.121	5.12	43	22.94	66.7	9.36 bu.
5	.215	12.34	58	20.24	58.9	4.11 bu.

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A Productivity Index (PI) for Estimating Erosion's Impact on Productivity

By Robert Dowdy, William Larson, and Fran Pierce

McCormack and Larson (1981), in discussing the impacts of soil erosion on crop yields, described an attempt to develop simplified soil productivity index models based on the physical characteristics of each soil horizon. The index was based on soil texture, coarse fragments, bulk density, and organic matter and was integrated over a 150-centimeter profile depth. Comparison with corn yield estimates from the SOILS-5 data base for the central Corn Belt indicated a moderate relationship between the two. They concluded that the soil productivity model needed improvement and that documented soil and crop yield data were difficult to find.

The remaining question at that time was, "Could a soil productivity model be developed that could utilize existing data in the 1977 National Resources Inventory (NRI) and the SCS-SOILS-5 data base and estimate the effects of erosion on long-term productivity?". In July of 1981, we began again to work with the model discussed by McCormack and Larson.

In our approach to the problem, three things were requisite: 1) a quantitative measure of soil productivity, 2) its rate of change due to erosion, and 3) the rate of soil erosion. In our conceptualization we assumed that the productive capacity (P) of a given land unit was a function of the soil productivity (SP), climate, topography, management factors, etc. We wanted to develop an index (SP') that was related only to the productivity of soil and hold other determinants of productive capacity constant. Our approach then was to: a) develop an estimator of or proxy for SP, b) select an indicator crop to represent P (for the Corn Belt region, we chose corn as the indicator crop), c) hold all the other determinants of P constant while we evaluated the proxy for SP, and d) if that proxy proved to be a good estimator of SP, then proceed to calculate SP' as a function of time and soil removed by erosion. Basically, our interests were to utilize data contained in the SOILS-5 and 1977 National Resources Inventory (NRI) to provide inputs to the index and the estimates of soil erosion. This would allow estimation of the rate of change in soil productivity with time and in doing so allow the assessment of long-term impacts of soil erosion on productivity.

Very early in our re-visit to the model discussed by McCormack and Larson, we discovered the productivity index work done by L.L. Neill (1979) at the University of Missouri-Columbia. She had taken an approach to a productivity index we thought would be appropriate. We began with Neill's model (Kiniry et al., 1983), the 1977 NRI, and the SCS-SOIL-5 data base for the purpose of estimating the impact of soil erosion on long-term soil productivity. Our assignment today is to discuss the development of the PI model, its validation and the results of its application to the soils in the Corn Belt region of the United States. Much of what we will discuss today is contained in published papers (Pierce et al., 1983, 1984a, 1984b) and unpublished reports prepared for the Soil Conservation Service.

Quantifying Soil Productivity

The soil productivity index developed by Neill (1979) and reported by Kiniry et al. (1983) was based upon the assumption that soil is a major determinant of crop yield due to the environment it provides for root growth (other factors being climate, management, and plant genetic potential). Kiniry et al. (1983) considered five soil parameters--available water capacity, bulk density, aeration, pH, and electrical conductivity--as the parameters most influential to root growth. Each parameter was evaluated in terms of root response, and each soil layer was weighted according to an ideal rooting distribution. Response of each soil parameter was normalized to range from 0.0 to 1.0. Kiniry et al. (1983) calculated PI using the following equation:

$$PI = \sum_{i=1}^{r} (A^i \times B^i \times C^i \times D^i \times E^i \times WF^i) \qquad [1]$$

where A is sufficiency of available water capacity (AWC)
B is sufficiency of aeration
C is sufficiency of bulk density
D is sufficiency of pH
E is sufficiency of electrical conductivity
WF is weighting factor and
r is the number of 10-centimeter increments in the rooting depth.

A sufficiency is a normalization over the range of a given parameter. PI takes on a value between 0 and 1, with 1 indicative of a soil with no limitations.

We modified Kiniry et al. (1983) model to include some additional concepts and to use data available from the SOILS-5 data base. This model for evaluating productivity is:

$$PI = E^{r} (A \times C \times D \times WF) \quad [2]$$

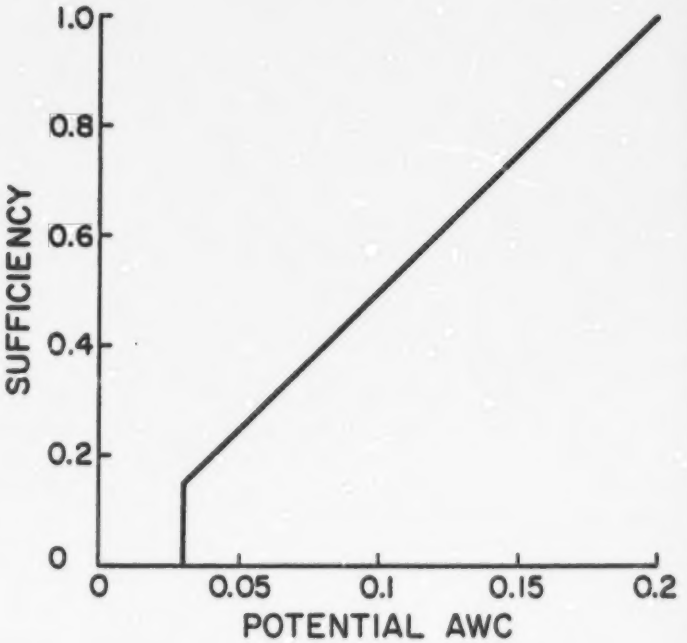
$$PI = E \prod_{i=1} (A^{i} \times C^{i} \times D^{i} \times WF^{i})$$

where A is sufficiency of AWC
C is sufficiency of bulk density (adjusted for permeability)
D is sufficiency of pH
WF is a weighting factor and
r is the number of horizons in the depth of rooting.

Following are brief descriptions of model parameters. More detailed descriptions can be found in Pierce et al. (1983).

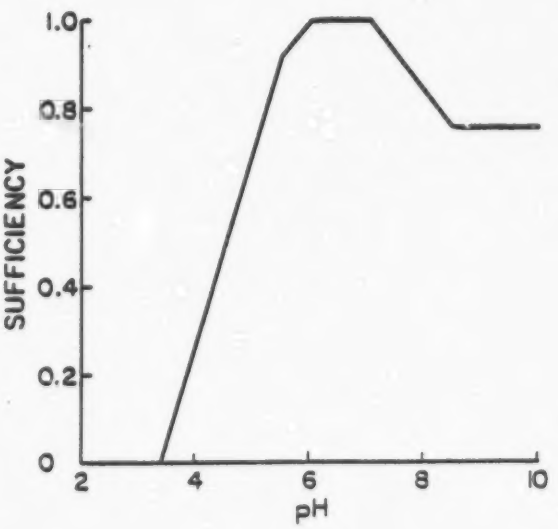
We used the sufficiency of available water capacity used by Kiniry et al. (1983), with the added condition that when available water capacity fell below 0.03 cm/cm, the sufficiency of available water was set to 0.0 (Figure 1). The value 0.03 is based upon Grossman and Berdanier's (1982) criteria for potential rooting depth in soils.

Figure 1. Sufficiency of available water capacity.



The sufficiency of pH used in this analysis is that used by Kiniry et al. (1983) except for the inclusion of a small reduction in the sufficiency when pH exceeds 7 (Figure 2).

Figure 2. Sufficiency of PH.



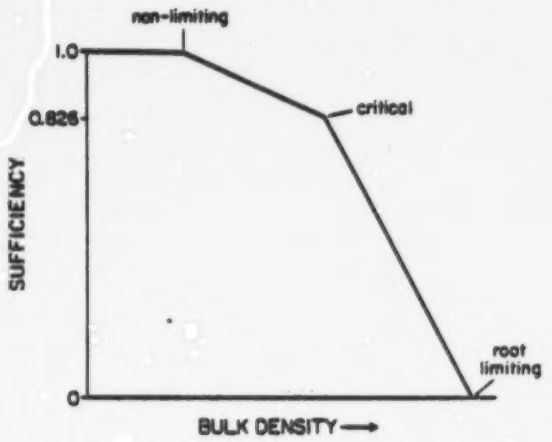
Since amendments, such as lime, effectively remove pH deficiencies, the sufficiency of pH was assumed to be 1.0 in the surface 20 cm.

The bulk density-sufficiency relationship proposed by Kiniry et al. (1983) utilized a single function for all soils. This was altered to incorporate the differences in sufficiency of bulk density for the various soil family texture classes. The sufficiency curve of bulk density takes the same form as that proposed by Kiniry et al. (1983) (Figure 3). However, the non-limiting, critical and root limiting bulk densities vary with family texture class (Table 1). The scheme for defining soil family texture class is based on the family texture classes as defined in Soil Taxonomy (United States Department of Agriculture, Soil Conservation Service, 1975) and is given in Table 2. The classes used are delineated on the textural triangle in Figure 4. The values in Table 1 were determined by Pierce et al. (1983). Within a family texture class, the sufficiency of bulk density was adjusted according to its permeability to account for soil horizons with high bulk densities but significant structural development, as indicated by permeability rate. The adjustment factor varies with family texture class and permeability as described by Pierce et al. (1983).

Table 1. Non-limiting, critical and root limiting bulk densities for each family texture class.

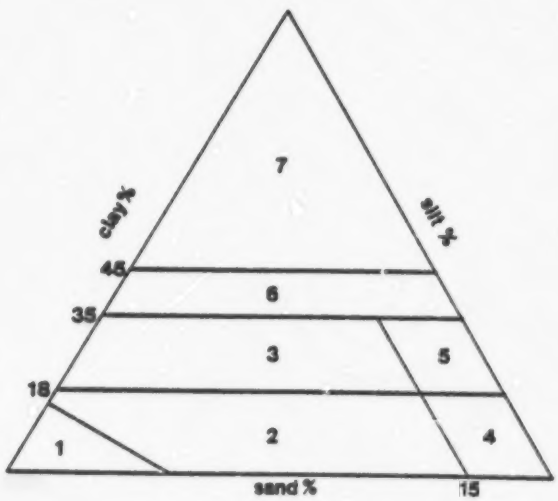
Family Texture Class	Non-limiting Bulk density	Critical Bulk Density	Root Limiting Bulk Density
	----------g/cm3----------		
sandy	1.60	1.69	1.85
coarse loamy	1.50	1.63	1.80
fine loamy	1.46	1.67	1.78
coarse silty	1.43	1.67	1.79
fine silty	1.34	1.54	1.65
clayey 35-45%	1.40	1.49	1.58
less than 45%	1.30	1.39	1.47

Figure 3. Sufficiency of bulk density.



To accommodate the effect of tillage on bulk density, the sufficiency of bulk density was assumed to be 1.0 in the surface 20 cm.

Figure 4. Soil family texture class.



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Kiniry et al. (1983) suggested a weighting factor representing an ideal rooting pattern for corn (Figure 5). They describe the predicted root fraction, RF, as:

$$RF = 0.350 - 0.152 \times \log (d + (d^2+6.45)^{0.5}) \quad [3]$$

Figure 5. Assumed rooting pattern (Weighting Factor) for 100 centimeter depth in an ideal soil.

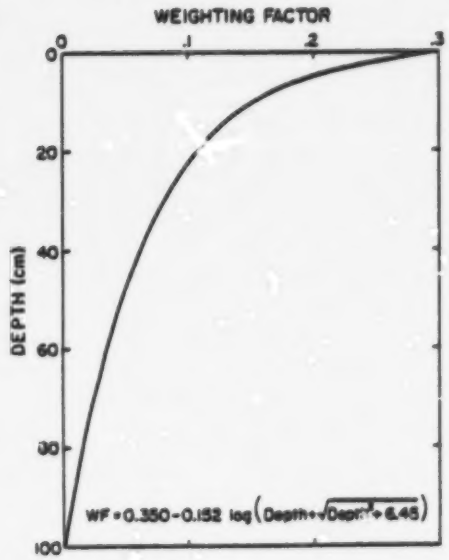

Table 2. Scheme for determining family texture class for each horizon or layer in a SOILS-5 record.

		Class
A. Clay >= 35%		
	35 - < 45%	6
	45 - < 55%	7
	55 - < 65%	8
	65 - < 75%	9
	> = 75%	10
B. Clay >= 18%		
	passing 200 sieve >85%	5
	else	3
C. Texture is one of the following: COS, S, FS, LCOS, LS, or LFS		1
D. Passing 200> >85%		4
E. Else		2

Our form of the weighting factor differs in that it is the integral of RF equation obtained using the identity:

$$[\log(x+(x^2+a^2)^{0.5})]dx = x[\log(x+(x^2+a^2)^{0.5}) - (x^2+a^2)^{0.5})] \quad [4]$$

The integral of the weighting factor equation is:

$$WF = 0.350d - 0.152[d(\log (d + (d^2+6.45)^{0.5}) - (d^2+6.45)^{0.5}) \quad [5]$$

The integral was normalized to a value of 1.0 and stored in centimeter increments to be utilized as a "look-up" table. The weighting factor (WF) for a given soil layer was interpolated from this table.

Sample Calculation

The Dubuque soil series (Typic Hapludalf, fine-silty, mixed, mesic) will serve as an example for calculating PI. The input data are given in Table 3. Table 4 gives the sufficiencies, weighting factors, and PI for each soil layer represented in the SOILS-5 data base for the Dubuque soil. To calculate PI, first determine the textural class based on the scheme given in Table 2. Then determine the sufficiency for each soil layer by calculating the sufficiency for each parameter (using the appropriate coefficients for the textural class), and interpolate the weighting factor from the weighting table prepared in advance. The product of the sufficiencies and WF determines the PI for each layer. The soil PI is the sum of the layer PI's as illustrated in Table 4.

Assumptions

Data in SOILS-5 are generally reported as ranges or classes of values. Values used to calculate PI were the midpoint of the range or class. We assumed fertilizers were not limiting. This

Table 3. Soil properties for the Dubuque soil series used as input to PI calculation as obtained from the SOILS-5 data base.

Texture	Depth cm	AWC cm/cm	Bulk g/cm3	PH	Clay %	Permeability in/hr	Passing 200 %
SIL	0-28	0.21	1.33	6.5	21.5	1.3	97.5
SIL	28-56	0.19	1.38	5.8	30.5	1.3	97.5
C	56-69	0.135	1.525	5.8	47.5	0.13	75.5

Figure 6. Location of soil surveys completed in the last eight years.

precluded assessment of the added fertilizer costs required to maintain yields. A soil's sufficiency as a rooting environment is affected by climate, and, therefore, geographic region. Water storage is more critical in areas Figure 5 where seasonal rains are insufficient or infrequent. In this analysis, a soil's productive potential would not vary by MLRA, but actual crop production would be higher in MLRA's with more favorable climate. Comparison of PI across large land areas, therefore, should not ignore climatic differences.

Model Performance

We evaluated model performance using (a) the relationship between estimated corn yields as reported in the county soil surveys and PI and (b) the relationship between Minnesota Crop Equivalent Rating (CER) (Rust and Hanson, 1975) and PI. Estimated corn yields are those expected under a high level of management. Crop equivalent ratings reflect the "relative net economic return per acre when managed for cultivated crops, permanent pasture, or for forestry, whichever use is computed as giving the highest net return" (Rust and Hanson, 1975). A CER of 100 is the highest rating.

Eight counties were selected for which soil surveys had been completed in the last five years (Figure 6). Figure 7 gives the scatterplots of CER versus PI in four Minnesota counties (Cottonwood (Rolling, 1979), Dakota (Hundley, 1983), Grant (Demartelaere, 1978), and Olmsted (Poch, 1980)). The R^2 for these regressions ranged from 0.63 to 0.71. R^2 increased an average of 26 percent, to a range of 0.79 to 0.90 by excluding Histosols, frequently flooded and depressional soils (circled points) and soils with slopes exceeding 6 percent (squares) for which PI was high relative to CER. The model predicts a higher productivity for these soils since it fails to account for insufficient aeration during a portion of the growing season in the case of wet soils and does not account for slope effects on yield in the case of more sloping soils.

Figure 8 gives scatterplots of estimated corn yield versus PI in Turner County, South Dakota (Kunze, 1982); Fayette (Kuehl and Highland, 1978) and Jasper (Nestrud and Worster, 1979) counties, Iowa; and Miami County, Indiana (Deal, 1979). Trends similar to those found in Minnesota concerning landscape position were evident in these counties. The slope and intercept of the regression lines are similar for each MLRA. The two exceptions are Turner and Grant counties, which are on the fringe of the Corn Belt. Based on the strength of the relationship between corn yield and CER with PI, the model performed well in the Corn Belt.

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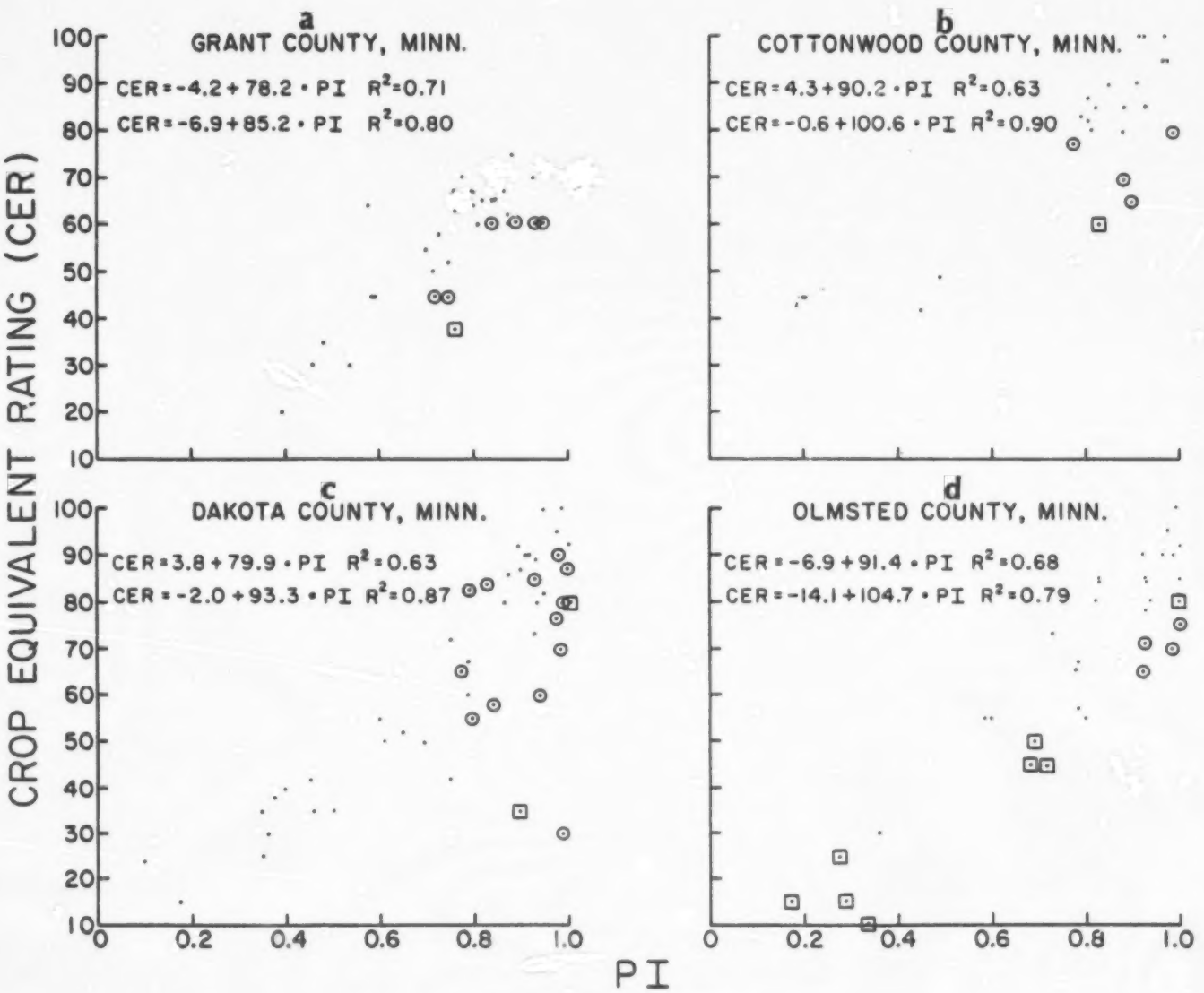
Table 4. Calculation of the sufficiencies, weighting factors, and PI for the Dubuque soil series.

Horizon Depth cm	Horizon Thickness cm	Texture Class	SUFF AWC	SUFF DB	SUFF PH	WF	Layer PI
20	20	5	1.000	1.000	1.000	0.341	0.341
28	8	5	1.000	1.000	1.000	0.095	0.095
56	28	5	0.950	0.970	0.968	0.266	0.240
69	13	7	0.675	0.000	0.968	0.100	0.000
bedrock	-	-	-	-	-	-	0.000
Soil Series PI							0.676

Figure 7. Crop equivalent rating for four Minnesota Counties.



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Long-term Changes in PI

The next step of our approach was to calculate the change in soil productivity as erosion removed the soil surface. Figure 9 shows diagramatically what was done. For each sample point in the 1977 NRI, the soil name was matched to the SOILS-5 data base. The data in the SOILS-5 data base provided the input to the PI model. The erosion rate recorded in the NRI for that point was converted to a depth increment. For example, after 50 years a certain depth would be eroded based on the NRI estimates. A soil thickness equivalent to that depth would be removed from the soil surface and the PI index recalculated. The change in productivity for that time period would be the difference between PI calculated without erosion and that calculated after simulated erosion removed the surface soil. Let me stress here that this analysis followed this procedure for every sample point in the 1977 NRI for the Corn Belt region of the United States. Pierce et al. (1984a) summarized the calculated changes in PI by slope class for every soil within the Corn Belt region. The change in PI after 100 years ranged from about 2 percent to a high of about 8 percent in MLRA 112 when the data were aggregated over the entire MLRA (Table 5). One problem associated with this sort of aggregation of data is the loss of the distribution of those soils that are highly vulnerable to erosion and have high erosion rates. The soil-by-soil analysis, although compiled, was never published. It was, however, incorporated in an extensive report prepared for the Soil Conservation Service in 1983. Table 6 summarizes the aggregated change in PI by slope classes for each MLRA in the Corn Belt. MLRA 103 is a substantial and highly productive area in south-central Minnesota and north-central Iowa. Most of the acreage in this area has slopes less than 6 percent. With the higher slopes, erosion rates increase and changes in PI get quite high (19 percent). Yet when aggregated over all acreage, the average reduction in P is about 3 percent. Overall, a 3 percent reduction in PI is small. However, a significant portion of the landscape in this MLRA is eroding at high rates and also is vulnerable to erosion in terms of productivity losses, a fact missed with average values. MLRA 105 has highly erosive soils with sloping land predominant. In the higher slope classes, the changes in PI are quite significant (40 percent). PI losses average about 6 percent for the MLRA as a whole. These losses are lower than they might have been since MLRA 105 has perhaps the best conservation practices of any MLRA in the Corn Belt, if not in the United States, as reflected in the average C and P values (Table 5). In the deep loess soils of MLRA 107, our analysis suggests that changes in long-term productivity will not be significant even at high erosion rates and to the preponderance of highly sloping land. This is due to the thickness and condition of the loess material. It is clear that (1) consideration must be given to the soil and its position in the landscape as well as the erosion rates, and (2) the distributional attributes of erosion induced productivity losses are important and these, and not the weighted averages, must be considered.

Table 5. Weighted average values of RKLS, C, P, V, PI and projected reductions in PI for each MLRA in the Corn Belt.

MLRA	RKLS $t\ ha^{-1}\ yr^{-1}$	C	P	V	PI	POTENTIAL REDUCTION R	ADJUSTED POTENTIAL REDUCTION RI	RP*	CHANGE IN PI
						---------- % ----------			
102A	21	0.28	0.99	-0.23	0.82	15.2	5.0	1.4	1.7
102B	74	0.30	0.97	-0.15	0.85	9.6	9.0	2.8	2.3
103	28	0.36	0.99	-0.36	0.86	20.7	9.0	5.3	5.1
104	54	0.31	0.99	-0.32	0.88	10.2	15.1	4.6	2.7
105	176	0.23	0.85	-0.27	0.83	16.1	45.6	7.4	6.4
106	90	0.28	0.81	-0.15	0.85	8.9	12.3	2.7	5.9
107	154	0.33	0.88	-0.13	0.92	7.1	14.6	4.2	2.7
108	74	0.33	0.95	-0.16	0.92	9.0	10.3	3.2	2.4
109	129	0.33	0.93	-0.19	0.80	11.9	23.7	7.4	7.1
110	29	0.40	0.99	-0.39	0.80	24.2	10.7	4.2	4.9
111	39	0.29	0.99	-0.39	0.71	27.6	16.3	4.8	9.7
112	56	0.29	0.96	-0.23	0.67	17.0	14.6	4.1	7.8
113	67	0.31	0.99	-0.27	0.73	16.4	18.8	5.8	4.4
114	56	0.29	0.97	-0.30	0.76	20.2	17.2	4.8	5.5
115	80	0.33	0.96	-0.16	0.83	9.7	11.8	3.8	3.9

Soil Vulnerability

When soil removed (cm) (or equivalently tons of soil per acre) is plotted against a measure of productivity such as PI, it is very clear that soils vary in their level of productivity and their

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Figure 8. Estimated corn yield versus PI for four counties in Indiana.

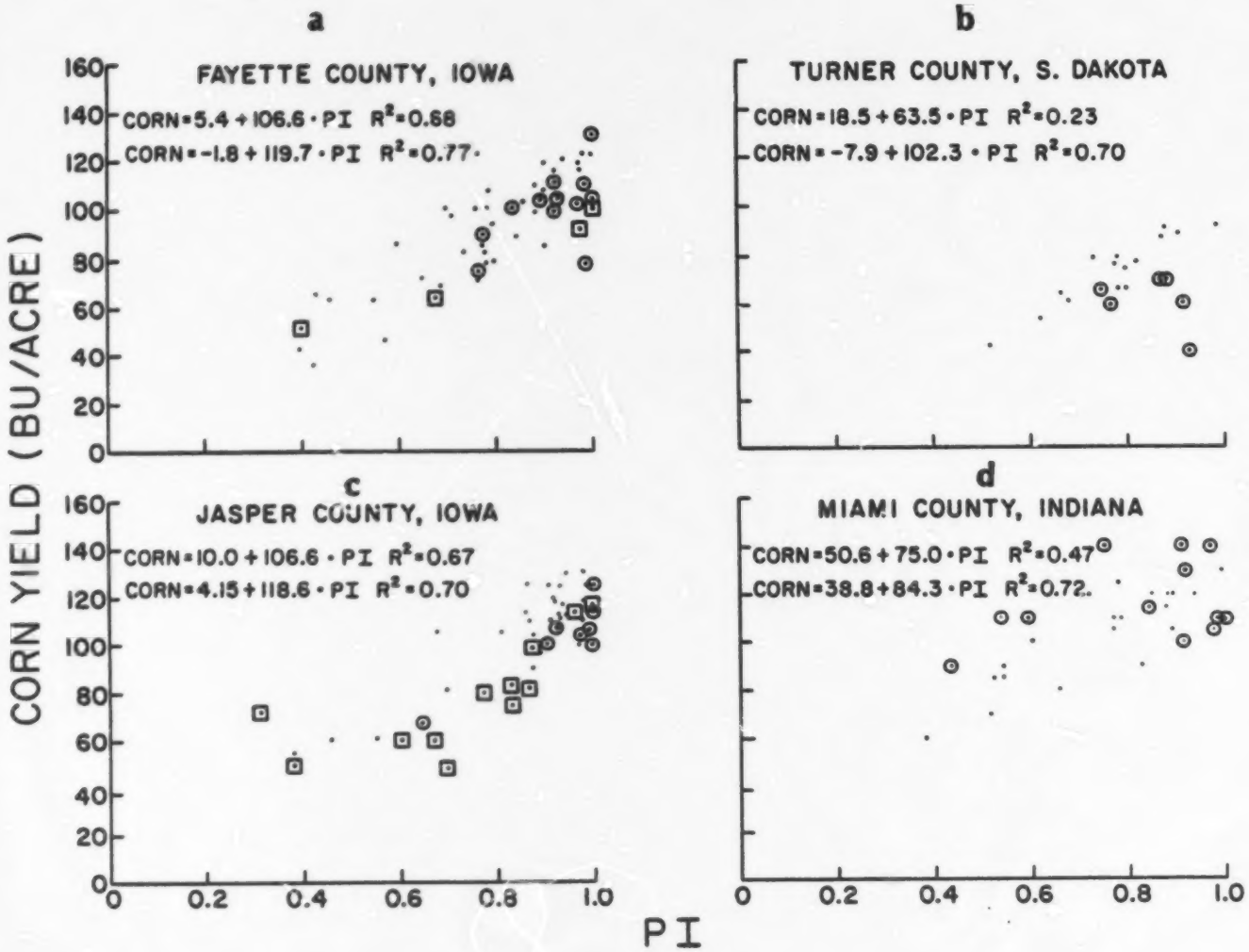

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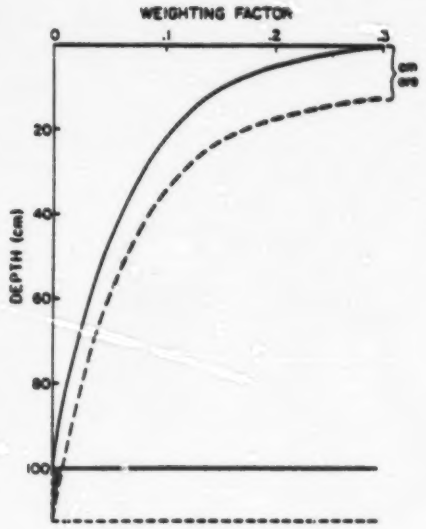
Figure 9. Concept of the Sliding Weighting Factor.



rate of change in productivity as soil is removed. For example, Figure 10 plots three soils which taxonomically are identical through the family level (Typic Hapludalfs, fine-silty, mixed, mesic). While taxonomically similar, these soils behave quite differently with respect to productivity responses to soil erosion. The order of productivity of these soils is: Fayette Miami Dubuque. The rate of change in productivity with soil removed follows the order Dubuque, Miami, and Fayette. The Dubuque is underlain by bedrock, the Miami soil has dense glacial till in the subsurface, and the Fayette is formed in deep loess deposits. Taxonomy classifies soils based on the control section which, at the family level of classification, considers a soil depth insufficient to answer erosion-productivity related questions. Such questions must consider the soil conditions that vary considerably below the control section. The role of taxonomy in answering erosion-productivity related questions is, therefore, limited.

That soils differ in their susceptibility to erosion induced productivity losses is important. Figure 11 plots PI versus soil removed by erosion for the Waukegon soil, a highly productive soil underlain by gravel at about 85 centimeters. The rate of change in PI with soil removed is directly proportional to the soil thickness. Pierce et al. (1983, 1984a) defined the vulnerability (V) of soil as the rate of change in productivity associated with soil removed or the slope of the PI versus soil removed curve. Pierce et al. (1984a) selected 50 cm as a reference depth of removal to calculate V. The V-value for the Waukegon soil is -0.75. V calculated for Corn Belt soil ranged from positive numbers, which indicate that productivity increased with soil removed, to values of -1.2, which would be a highly vulnerable soil in our classification.

Table 6. Hectares in cropland and weighted average erosion rate (NRI, 1977), and change in PI by slope class, and initial PI for each MLRA in the Corn Belt.

MLRA	SLOPE	HECTARES	ESTIMATED EROSION	PI	CHANGE IN PI		
					--- years ---		
	%	(1000's)	t/ha/yr	initial	25	50	100
					------ % ------		
103A	0-2	884	2		1	1	1
	2-6	1291	7		1	1	2
	6-12	158	18		1	2	3
	12-20	18	32		2	4	6
	TOTAL	2351	6	.82	0.7	1.0	1.7
103B	0-2	950	4		0	0	1
	2-6	1094	11		1	1	2
	6-12	530	45		2	3	5
	12-20	106	91		2	2	3
	20-45	4	184		2	3	7
	TOTAL	2702	19	.85	0.9	1.3	2.3
103	0-2	2787	3		0	0	1
	2-6	1932	11		1	2	4
	6-12	374	40		3	7	15
	12-20	45	82		7	13	19
	20-45	9	146		3	6	10
	TOTAL	5147	10	.86	0.8	1.6	3.1
104	0-2	846	3		0	1	1
	2-6	763	13		1	1	3
	6-12	130	37		2	4	8
	12-20	26	80		2	3	4
	20-45	6	130		4	2	0
	TOTAL	1971	13	.88	0.7	1.4	2.7
105	0-2	178	4		0	0	1
	2-6	524	12		1	1	3
	6-12	482	24		2	3	5
	12-20	217	59		6	13	20
	20-45	14	210		12	28	40
	TOTAL	1415	24	.83	1.9	3.8	6.4
106	0-2	402	6		1	1	1
	2-6	599	16		2	4	7
	6-12	460	34		4	6	9
	12-20	28	109		4	5	5
	TOTAL	1498	21	.83	2.5	3.9	5.9
107	0-2	833	5		1	1	1
	2-6	1157	18		1	1	2
	6-12	819	61		2	3	5
	12-20	376	114		2	3	4
	20-45	12	306		2	2	2
	TOTAL	3217	38	.92	1.0	1.8	2.7

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Table 6. Continued.

MLRA	SLOPE	HECTARES	ESTIMATED EROSION	PI	CHANGE IN PI		
	%	(1000's)	t/ha/yr	initial	--- years ---		
					25	50	100
					------ % ------		
108	0-2	2883	6		0	0	1
	2-6	2171	17		1	1	2
	6-12	989	42		2	4	6
	12-20	198	94		5	7	8
	20-45	9	214		6	6	5
	TOTAL	6024	19	.91	0.9	1.3	2.4
109	0-2	394	8		1	1	2
	2-6	432	23		2	3	5
	6-12	390	62		6	10	13
	12-20	56	188		7	8	9
	20-45	3	337		30	39	39
	TOTAL	1275	38	.80	3.0	4.9	7.1
110	0-2	1034	4		0	1	2
	2-6	512	17		2	4	9
	6-12	19	59		16	32	48
	20-45	6	298		39	48	48
	TOTAL	1571	10	.80	1.4	2.8	4.9
111	0-2	3289	4		1	1	3
	2-6	1703	12		2	4	8
	6-12	538	38		6	12	22
	12-20	47	75		14	26	36
	>45	3	928		61	61	61
	TOTAL	5580	10	.71	1.6	3.1	5.7
112	0-2	845	11		1	2	4
	2-6	806	21		3	6	11
	6-12	14	24		4	9	17
	12-20	3	131		51	79	100
	TOTAL	1668	16	.67	2.2	4.2	7.8
113	0-2	699	6		1	1	2
	2-6	384	27		2	3	6
	6-12	67	67		7	11	13
	12-20	9	149		8	20	38
	20-45	3	602		7	7	7
	>45	3	379		29	6	0
	TOTAL	1164	19	.73	1.6	2.7	4.4
114	0-2	829	6		1	1	2
	2-6	498	18		3	4	7
	6-12	120	46		6	12	21
	12-20	3	28		1	2	4
	TOTAL	1451	14	.75	1.7	3.0	5.5
115	0-2	1577	7		0	1	1
	2-6	1275	21		1	2	4
	6-12	459	59		4	7	10
	12-20	79	126		4	5	6
	20-45	6	207		2	3	2
	TOTAL	3396	22	.83	1.4	2.3	3.9

The relationship between the erosion rate and change in PI averaged over each MLRA in the Corn Belt region is weak (Figure 12). The inherent differences in soils within each MLRA reflect the differences in vulnerability. Therefore, it is not only the erosion rate but the vulnerability that is important in evaluating erosion's impact on productivity. Soils with high vulnerability (based on our definition) can sustain productivity damages at low erosion rates.

Figure 10. Productivity responses to soil erosion for three taxonomically identical soils.

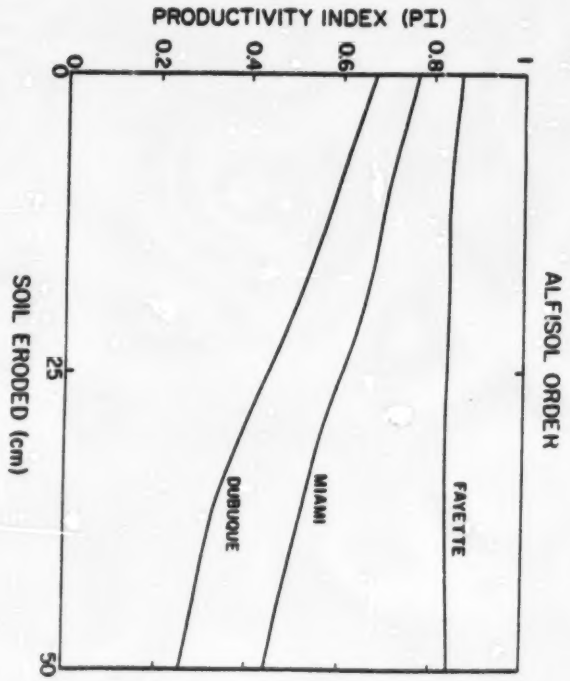

Figure 11. Production loss as soil is eroded on Waukegan soil.

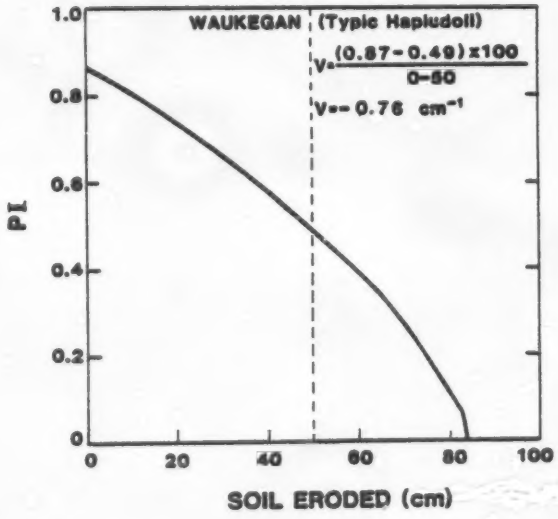

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Figure 12. Relationship between erosion rate and change in PI for selected MLRA's.

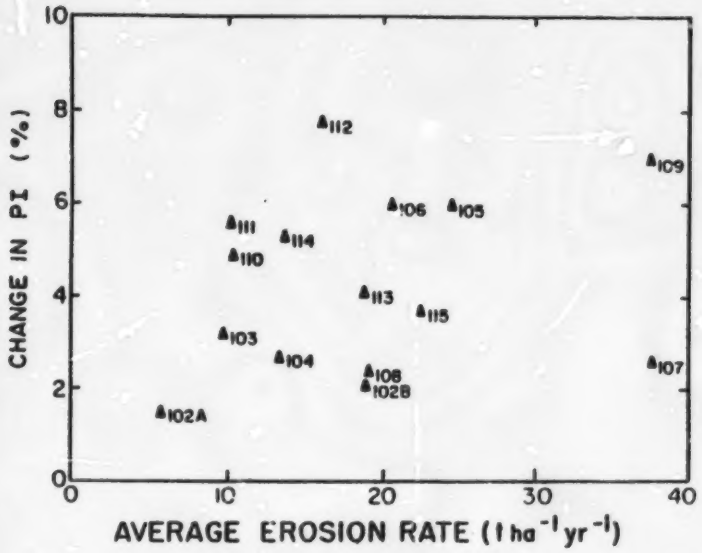

Figure 13 illustrates the distribution of vulnerability (V-values) for each MLRA. The total bar represents the total NRI acreage reported within each vulnerability class. The blackened area within the bar represents cropland acreage. It is significant that all MLRA's, on the average, have negative vulnerabilities. This means that each has the potential for productivity reductions from erosion, but to varying degrees. The distribution of vulnerable soils lends itself to establishing a criteria for which soils would be taken out of production and which soils might be classified as fragile lands.

The data in Table 5 illustrates why consideration must be given to both the erosion rate and vulnerability. MLRA 107 has the highest erosion potential as measured by the RKLS product of the USLE. In terms of potential for erosion, MLRA 107 must be considered the most susceptible to erosion damage. MLRA 107 was identified in the 1982 RCA as a critical eroding area. MLRA 103, on the other hand, is very susceptible to erosion induced productivity losses as indicated by V. Therefore, if only potential for damage were the criteria, MLRA 103 would be in need of the most protection. The answer lies with the combination of the two which can be addressed in the following manner.

Pierce et al. (1984a) defined R as a potential reduction in productivity if 50 cm of soil were removed uniformly across the entire landscape of the Corn Belt. There are four MLRA's in the Corn Belt which show a potential for a 20 percent reduction in PI on a weighted average basis and would be considered highly vulnerable. By combining vulnerability with a measure of the potential for erosion, an adjusted potential reduction, R', can be calculated as follows:

$$R' = -(RKLS \cdot V \cdot a \cdot t)/PI \qquad [6]$$

where RKLS is obtained from the USLE,

V is soil vulnerability,
a is the allowable reduction in PI, and
t is the planning horizon in years.

R' would identify soils, regardless of land use, that would have the potential for productivity loss in terms of both erosion rates and vulnerability. Multiplying R' by C and P of the USLE provides an estimate of the actual PI losses which might occur if current erosion rates were sustained for a long period of time. Considering

Table 5 once again, MLRA 107 has an estimated weighted average erosion rate of 38 tons per acre per year while MLRA 103 averages 10. The order of the potential for PI reduction (R) is reversed. MLRA 105 has an intermediate erosion rate and R. However, it has the highest adjusted potential reduction (R'). Without any practices on the land (C and P equal to 1), soils in MLRA 105 would experience significant productivity reductions. Fortunately, conservation practices in MLRA 105 are evident and reduce actual productivity losses to a fraction of potential losses.

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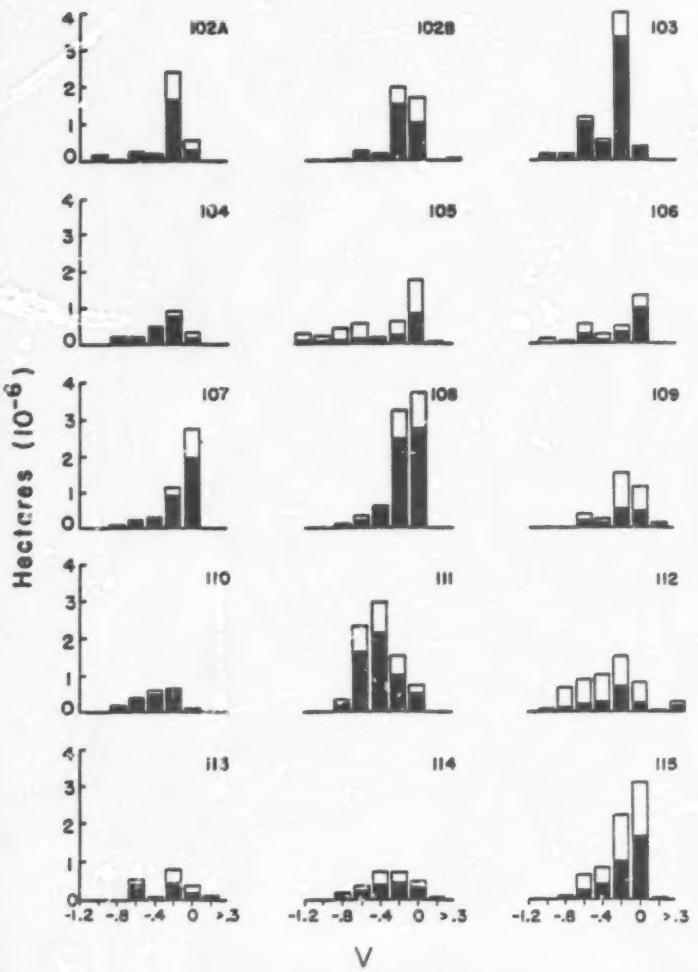
Figure 13. Distribution of Vulnerability (V-values) by MLRA.



T Values

A concept of great importance concerns the extent to which erosion can be tolerated. Much discussion has centered on T-values. If a multiple definition of T-value can be agreed upon, where T1 is the erosion rate corresponding to a specified reduction in productivity within a given planning horizon and T2 would reflect other erosion concerns, one can relate the productivity of soil and its vulnerability, and calculate T1 values (Pierce et al., 1984b).

$$T1 = [a \cdot PI \cdot k]/(V \cdot t \qquad [7]$$

where k is a conversion factor to convert tons per unit area to a depth and other parameters are defined above. Figure 14 plots T1 versus V using equation [6] for various values of a and t. Curves A, B, and C are calculated with a set to 5 percent and t set at 100, 200, and 50 years, respectively. At V values exceeding -0.2 (soils with low vulnerability to erosion induced productivity losses), T1 values are large or undefined by equation [6] and some other erosion concern will dictate the T value. About 89 percent of the soils in the Corn Belt have V-values smaller than -C.2, leaving 11 percent for which T1 is large or undefined.

Table 7 lists traditional T-values and calculated T1 values for soils in Dakota County, Minnesota, to illustrate the usefulness of Equation [6]. These T1 values were calculated assuming a 5 percent reduction in PI was tolerable in 100 years. It is clear that this definition of T1 reflects some of our notions about soils that have present T values of less than 5 tons per acre per year.

Figure 14. Erosion and Vulnerability (V) relationships.

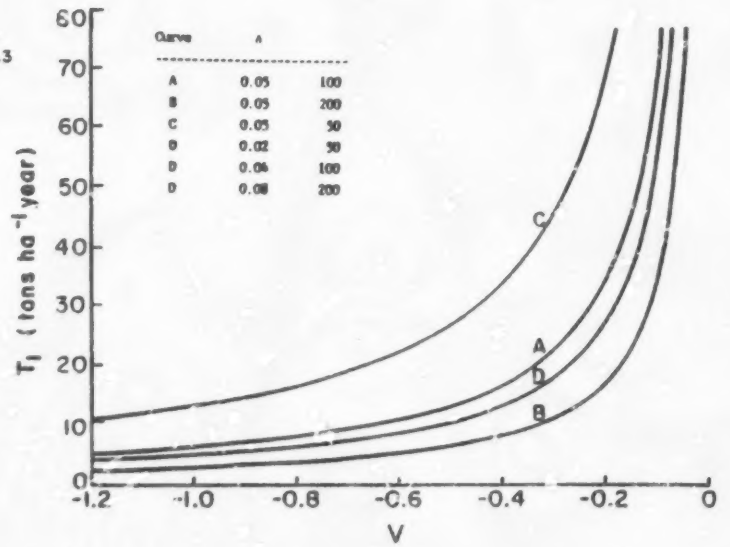


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Table 7. PI, V, and TI (with W - 0.05 and T - 100 years) for soil series in Dakota County, Minnesota.

SOIL SERIES	PI	v=100	T t/ha/yr	TI	SOIL SERIES	PI	v=100	T t/ha/yr	TI
ALGANSEE	0.369	-0.202	5	5.8	KLINGER	0.934	-0.268	5	10.6
ANTIGO	0.695	-0.568	4	4.0	LAWSON	0.958	-0.407	5	7.8
AUBURNDALE	0.753	-0.400	5	6.1	LE SUEUR	0.894	-0.217	5	12.4
BLOOMING	0.916	-0.169	5	16.6	LESTER	0.872	-0.188	5	14.0
BOLD	0.991	0.000	5	ND	LINDSTROM	0.999	-0.005	5	ND
BOONE	0.351	-0.284	4	4.4	MAHTOMEDI	0.383	-0.178	5	7.6
BOOTS	1.000	0.000	5	ND	MARLEAN	0.577	-0.470	2	3.9
BRODALE	0.336	-0.178	2	5.2	MARSHAN	0.829	-0.744	4	3.4
BURKHARDT	0.296	-0.792	3	1.6	MAXFIELD	0.918	-0.291	5	9.7
CARMI	0.754	-0.586	4	4.2	MAXCREEK	0.967	-0.185	5	16.0
CHETEK	0.253	-0.746	3	1.7	MAYER	0.789	-0.745	4	3.1
COLO	0.976	-0.067	5	41.6	MERTON	0.947	-0.166	5	17.3
COPASTON	0.505	-1.010	2	1.7	MINNEISKA	0.778	-0.178	5	15.1
CORDOVA	0.900	-0.341	5	7.9	OSHAWA	0.921	-0.079	5	31.9
CRYSTAL LAKE	0.842	0.167	5	ND	OSTRANDER	0.936	-0.197	5	15.9
CYLINDER	0.775	-0.917	4	2.7	OTTERHOLT	0.752	-0.567	5	4.9
DICKINSON	0.599	-0.506	4	4.8	PALMS	0.987	-0.160	2	4.8
EMMERT	0.106	-0.213	2	1.7	PLAINFIELD	0.360	-0.175	5	6.9
ESTHERVILLE	0.452	-0.963	3	1.9	PORT BYRON	1.000	0.000	5	ND
ETTER	0.756	-0.429	4	5.5	QUAM	0.342	-0.214	5	7.4
FAXON	0.796	-0.000	4	2.9	ROCKTON	0.786	-0.894	4	2.6
FRONTENAC	0.886	-0.613	4	4.5	ROMDEAU	1.000	-0.450	5	7.8
GARWIN	0.981	-0.072	5	40.3	SALIDA	0.174	-0.348	3	1.6
GLENCOE	0.988	-0.157	5	19.6	SEELYEVILL	0.989	0.000	5	ND
GOTHAM	0.486	-0.087	5	18.8	SPARTA	0.457	-0.234	5	5.7
HAMEL	0.958	-0.281	5	10.2	SPENCER	0.843	-0.498	5	5.6
HAVICK	0.358	-0.369	3	1.8	SPILLVILLE	0.985	-0.032	5	ND
HUBBARD	0.373	-0.271	5	4.7	TALLULA	0.952	-0.102	5	24.9
JEWETT	0.846	-0.459	5	6.8	TERRIL	0.973	-0.176	5	17.8
JOY	0.988	-0.022	5	ND	TIMULA	0.965	0.000	5	ND
KALMARVILLE	3.848	-0.467	5	6.2	WADENA	0.787	-0.894	4	2.8
KANABANZI	0.631	-1.172	4	1.7	WALKEGAN	0.866	-0.754	4	3.7
KATO	0.927	-0.649	4	4.2	WEBSTER	0.911	-0.291	5	9.6
KENNEBEC	1.000	-0.812	5	ND	WINNEBAGO	0.856	-0.894	5	26.6
KINGSLEY	0.649	-0.897	5	21.1	ZUMBRO	0.588	-0.109	5	15.6

ND - Not Defined by Eqn. (6) ie., V equals or exceeds 0.0).

Conclusions

These are some of the concepts that we have developed for the evaluation of erosion's impact on soil productivity. We believe these concepts to be very useful. We feel that the productivity index (PI) was a good estimator of or proxy for soil productivity for rainfed corn under a high level of management in the Corn Belt region of the United States. The changes in productivity for soils in MLRA's comprising the Corn Belt were less than 8 percent over the next 100 years when aggregrated on an MLRA basis. Significant losses were projected for some soils which are both vulnerable and eroding at significant rates. Soils with these characteristics can be identified only when the distribution of the data and not the weighted averages are considered. Changes in PI are reported here for slope classes within each MLRA indicating significant reductions in PI on highly sloping land in many MLRA's.

We found that the historical notion that changes in productivity are directly proportional to the erosion rate was not complete. This was due directly to the differences in vulnerability among soils and regions of the Corn Belt. It is important that both the vulnerability of soils in combination with estimates of soil erosion rate be used to determine the impact of soil erosion on productivity and the distribution of fragile lands in the United States.

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Question: How do you define soil vulnerability?

F. Pierce: One could plot the productivity index versus centimeters eroded or it could be put in terms of tonnage, but some measure of soil removal, the slope of that line, is the vulnerability (V) of that soil. Although not linear, for operation purposes we defined V as the slope of a linear segment between 0 centimeters and 50 centimeters of soil removed, and multiplied times 100 to obtain a workable number. The discussion of V values is contained in those papers in the Journal of Soil and Water Conservation, January-February, 1983, and 1984. The Soil Conservation Service has had the output of the soil-by-soil analysis for a year and a half. In addition, there are some copies of that floating around. Probably the richest part of the analysis is contained in that soil-by-soil analysis. We did look at the distribution by slope and the change in PI with time by slope class for each soil in NRI.

Question: In the case of the T values that you calculated, what happens at the high erosion rates for those soils that have high T values?

F. Pierce: Assuming a multiple definition of T soils with high or undefined T_1 values would have T determined by offsite concerns, landscape dissection, crop wash out, etc. This concept could incorporate wind erosion, but I'm not quite sure how you add wind and water erosion together. About 11 percent of this land in the Corn Belt falls in that region where T can't be defined with that equation. These are the very deep silty loam soils.

Question: How can either EPIC or PI reflect the disruptions to crop growth that are worse at higher slopes?

F. Pierce: If you look at studies that investigated the yield relationships between slope and the condition on the surface of the slope, there's a higher yield reduction due to the slope than that due to the eroded condition. I've wondered if we can separate out the effects of the slope versus the condition of the surface. Daniels and his coworkers in North Carolina have the Cecil soil and found that if they've got the

landscape position exactly right, they have not been able to show an effect due to the erosion. Landscape position dominates the productivity relationships. It is difficult to sort out erosion effects from landscape position. I don't know how we're going to work that one out, but that's important.

Question: Are these slope positions reflected in the soil data bases?

F. Pierce: Our soils data bases need a lot of work. That's not a criticism of anyone. It takes a tremendous amount of money and a tremendous amount of effort, as you well know. You've tried to put one together. We didn't have to compile data--we used what was there. Slope position is generalized in the soils data bases at best.

Question: Has the PI model been extended beyond the Corn Belt?

F. Pierce: Not by us. There are other people that have picked it up and are going ahead with its use in other states. I have no idea how many of them there are, or who they are. I just know from word of mouth that, for example, that New York has taken and modified it as well as Kentucky.

COMPARABILITY OF ESTIMATES

By Klaus Alt

We have now heard about three major modeling efforts which attempt to estimate the impact of erosion upon crop yields in specific resource situations. One of our objectives for this meeting is to evaluate how successful these efforts have been. Before we get to that evaluation and to a comparison of the results of these models, let me briefly summarize the important differences among the models.

The Yield/Soil Loss Simulator

The yield/soil loss simulator (Y/SL) was developed for the 1980 RCA Appraisal. The Y/SL was intended to summarize the results of the preceding experimental studies, as those had been reflected in the published soils and yield data. The Y/SL expressed the crop yield for each of 10 crops in 21 Water Resource Regions (3 of the 18 WRR subdivided) as a function of soil depth (by horizon), land slope, land capability subclass, soil texture, geographic location in the WRR, and differentiation between dryland and irrigated. THe functional relationship was estimated by regression analysis,hseparately for each of the 210 equations, from the data published in county soil surveys and other published sources. A computation exogenous to the model derived the expected erosion levels of alternative crop management systems (extended 50 years). These erosion levels were used to adjust the soil depth values, and the expected change in yields could then be derived by comparison of the regression forecasts for the yield values computed for each of the soil depth parameters. This process ignored yield changes caused by future improvements in technology and management. The reliability of the results of the Y/SL systems depends on the quality of the input data. Since the sources used in the Y/SL system were published over a long period of time, some of the data were not as comparable as they would have to be in a regression framework, and certain normalizing procedures had to be used to overcome these data problems. It is unclear how much influence these data problems had upon the results of the analysis.

The Erosion Productivity Impact Calculator

A contemporary critique of the Y/SL held the view that the Y/SL understated the effects of erosion compared to the effects shown by the experimental studies. This criticism was also voiced within the RCA process, where it led to the development of a multi-agency research task force on erosion impact modeling. This erosion impact modeling task force was led by ARS and included researchers from SCS and ERS. The eventual outcome of the modeling research was the Erosion-Productivity Impact Calculator (EPIC). EPIC is a detailed process model which simulates the growth of particular crop

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plants as a function of environmental and physical parameters, as well as the cropping system, management strategy, tillage, and conservation alternatives. The process simulation in the model quantifies the relationships among these parameters and simulates how the parameters change over time as erosion takes place. EPIC is unique among these three models in as much as the erosion amount is determined endogenously in the model, rather than exogenously imposed as in the other two models. EPIC analyzes how the parameters change in daily time steps over long periods (100 years or more), in response to physical processes including weather, hydrology, wind and water erosion, plant nutrient movement, plant growth, soil tillage and management, and plant environment control. The interactions among these parameters and processes are so many fold and complex that a complete simultaneous process model, such as EPIC can always be improved as additional research uncovers new ways to quantify and estimate these interactions.

EPIC uses a general plant growth submodel with crop-specific parameters to simulate the plant growth of corn, wheat, grain sorghum, soybeans, cotton, peanuts, alfalfa, and other grasses. In the RCA process, EPIC estimates were derived for these crops (as regionally appropriate) in each of the 168 Major Land Resource Areas in the contiguous 48 States on four soil capability classes (IIe, IIIe, IVe and VIe).

The Productivity Index

The Productivity Index (PI) model was developed independently of the preceding two models, although it responds to the identical research need. Rather than derive a regression relationship between yield and past erosion (as the Y/SL did) or estimate future yield as an output of simulated physical processes (as EPIC did), the PI model takes a more direct approach. The PI model starts from the hypothesis that the major effect of erosion is to change the soil's micro-environment for root growth and, thus, crop yield. Consequently, the PI model estimates the erosion effects by deriving the relationships between erosion and changes in the major determinants of the soil's capacity for root growth. In the PI model these major determinants are assumed to be: available water capacity, bulk density (adjusted for permeability), and pH. Since the lower soil horizons often have conditions of these three parameters that are less favorable to crop growth, the productivity index will be lowered as erosion uncovers these lower soil horizons. The relationships in the PI model have been derived and tested only for the Corn Belt, primarily with corn as the target crop. It is likely that other regions with different climates may have significantly different relationships; research is under way to allow for such regional adjustments. In the work done so far, based on the strength of the relationship between corn yield and the Minnesota Crop Equivalent Rating with PI, the model's authors concluded that the PI model performed well in the Corn Belt.

Comparison

It is always desirable to check the results of a computer model against the actual outcomes of the real world process which the model claims to simulate. The erosion process presents a problem because its effect upon soil productivity is (generally) so gradual that the year-to-year decrease in productivity may be smaller than the measurement error on crop yields. Consequently, only long-term observations of the erosion/productivity relationship are useful; however, there are only a few such experiments available in which full experimental controls were maintained over many years. It is intuitively appealing to compare the productivity of otherwise identical soils which vary by their past erosion levels and which are now classified in different erosion phases; however, it is not clear that such a comparison is proper because the ceteris paribus requirement may not be fully met. It is possible that the past erosion levels for two otherwise identical soils vary primarily because the slope gradient varied, and that the difference in gradient may be accompanied by differences in subsurface drainage or any other factors which has an influence upon soil productivity. Any such influence may overwhelm the erosion-induced productivity difference. As a result of this data difficulty, the primary basis for validation and acceptance of any erosion/productivity model is how closely the model projections match professional judgements of knowledgeable

researchers or, at least, how closely the model assumed options and specifications correspond to the professionally accepted "truths." A secondary basis for validation is the comparison of one model's results against other models' results. Clearly, this validation is weaker, since it is possible that all models are equally wrong.

In terms of these two validation methods, the Y/SL probably falls shorter of acceptability than the other two models. One problem relates to the ceteris paribus assumption for soil series in different erosion phases. The other problem is that the Y/SL uses soil characteristics from soil surveys which were published over a period of twenty years or more. During the intervening twenty years, new insights and measurement techniques have been developed which mitigate the strict comparability of assumptions, relationships, and data among the soil surveys. To state this is not to indict the effort; the Y/SL represented a much needed first approximation of a nationally consistent set of estimates and it spawned an area of research which resulted in the other two models.

Both the PI and EPIC models have had quite extensive review and are professionally accepted. The assumptions and specifications of both models have been published and scrutinized, so they meet the first criterion. They also meet the comparability criterion, as shown in Table 1. The table presents a summary of results derived by each model for an identical set of sample soils (one IIe soil in each of the 15 MLRA's in the Corn Belt, etc.). In the computations of yield effects, both models were constrained to the identical erosion level in each pairwise comparison. The table shows only the average, namely that both models estimate essentially the same overall effect of erosion over 50 years if current cropping practices continue without adjustments. The data in Table 1 does not show the pairwise comparisons, e.g. the difference in projections for the IIIe soil in MLRA 111. These pairwise differences are not negligible; on 9 soils EPIC shows a yield decrease at least 5 percentage points higher than the PI model,[1/] while on 4 soils the PI projection is more than 5 percentage points higher than EPIC's. Still, on 31 of 44 soils, the projections agree within ± 5 percentage points, which means that they essentially predict the same values, given a reasonable allowance for measurement and rounding errors in the models.

Table 1. Frequency Distribution of Erosion - Induced Productivity Losses Over 50 Years on Soil in 15 Corn Belt MLRA's

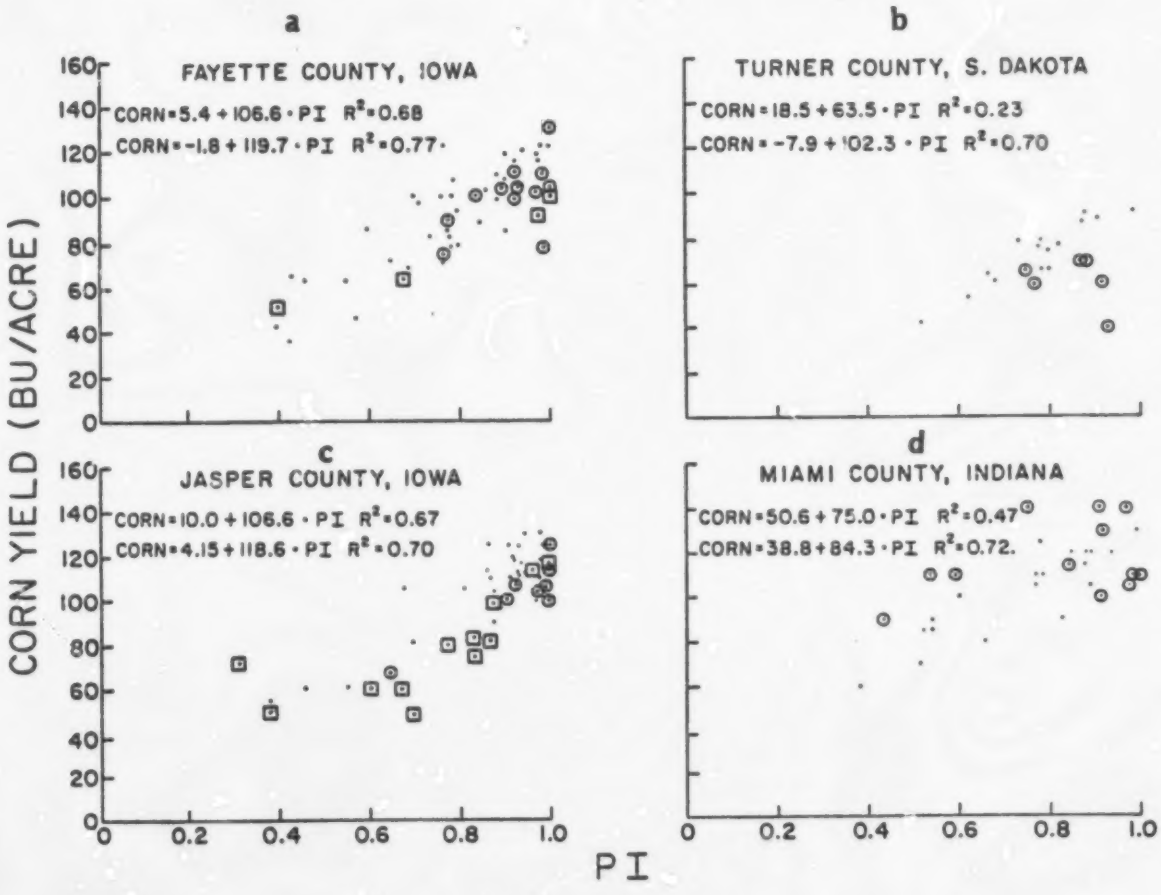
Item	Estimated by EPIC model	Estimated by PI model
Number of IIe soils with:		
1% decrease in productivity	2	7
1-5% decrease in productivity	12	6
5-10% decrease in productivity	1	2
10% decrease in productivity	--	--
Average decrease in productivity	2.7%	2.0%
Number of IIIe soils with:		
1% decrease in productivity	2	1
1-5% decrease in productivity	7	9
5-10% decrease in productivity	5	3
10-20% decrease in productivity	1	2
20% decrease in productivity	--	--
Average decrease in productivity	5.0%	4.1%
Number of IVe soils with:		
1% decrease in productivity	2	3
1-5% decrease in productivity	5	7

1/ For example, on the IVe Shelby soil in MLRA 109, EPIC projects a yield decrease of 6.7 percent compared to a PI projected decrease of 1.2 percent.

Table 1. Continued.

Item	Estimated by EPIC model	Estimated by PI model
5-10% decrease in productivity	3	21
10-20% decrease in productivity	4	2
20% decrease in productivity	--	--
Average decrease in productivity	6.6%	4.4%

Figure 8. Estimated corn yield versus PI for four counties in Indiana.



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GENERAL DISCUSSION

J. Putman: PI and EPIC turn out to be very similar. The Yield Soil Loss model shows a greater loss. There is a very key difference between Yield Soil Loss Simulator and PI-EPIC values. PI and EPIC both work with soil productivity. Yield Soil Loss worked with yields on eroded phases which included all erosion damage. This is perhaps a clue we should be looking at. I think there is a very key difference between the two data sets and the two model structures.

Yield Soil Loss Simulator is a regression model based on yields by erosion phase which includes annual damage concept. This may explain some of the erosion/productivity differences between Yield Soil Loss Simulator and the other two models.

P. Crosson: Is it possible that the Yield Soil Loss Simulator does not include replacement of fertilizer whereas the other two models do?

K. Flach: I made a list of PI and EPIC shortcomings from the meeting at the Purdue Conference on the "Impacts of Erosion on Soil Productivity." Both PI and EPIC are only simulating some of these differences for the simple reason that the knowledge is not available today. These differences have to do with the changes in surface soil characteristics and, consequently, runoff and, therefore, effective moisture for the crop due to erosion. That can be a very strong influence. So neither of them catch that. We have some nice data from ARS in Georgia, which shows that the eroded spots in a field had absolutely no moisture recharge during the summer, whereas the uneroded parts of fields had a moisture recharge. The point has been made before, that in part this is a function of position in the landscape, and in part it's a function of erosion; but it's both factors and we don't know now to unravel the two of them. There are components of soil erosion productivity relationships that are not being caught by either model. Then, we have the other factor, whether the models indeed reflect the differences in fertility loss that were not compensated and, again, what we see from the various field experiments on erosion productivity that are being conducted is that normally the farmer will not fully compensate for the fertility loss due to erosion. Typically, the farmer takes an average soil sample from the field and does not pick up the eroded spots. In the Georgia and Indiana models, data show that eroded spots are not producing at the full rate of their capability.

F. Pierce: Are those field estimates for the severely, moderately, and slightly eroded based on the same landscape position? Do the slight, moderate, condition and a severe erosion condition occur at the same position in the landscape?

D. Young: I wonder if either the PI model and the EPIC might be overlooking other very important causes of long-run changes in productivity. Two things come to mind:

(1) Tillage erosion appears to not be incorporated but could be. In some geographic areas, for example the Pacific Northwest, tillage erosion is very, very significant. Soil scientists there are studying the complete denuding of the hilltop "nobs" in the Palouse. Tillage erosion appears to be more important than sheet and rill water erosion in this denuding process.

(2) In terms of the long-run productivity consequences of erosion, the interaction between technical progress and erosion can have a much greater impact on reductions in future potential yields than direct erosion impacts. We discussed those points before at the 1982 RCA Symposium.

We need to address this latter issue. In the Palouse, for example, with winter wheat, we have been able to show that topsoil depth and technical progress have been complementary. But that is for only one region and one crop. As others have noted, it may be quite different in other regions and for other crops. The 1980 RCA assumed the same nature of interaction between topsoil depth and

technology for every crop in every region in the country. If that assumption is wrong, the productivity results are going to be incorrect.

D. McCormack: The crop yield data that were analyzed by the Yield/Soil Loss Simulator by Dyke and Hagen were yields by soil map units under an assumed high level of management. Yield estimates were included for the eroded map units as well as for the equivalent uneroded map units. The same amount of fertilization was thus assumed, but no compensatory fertilizer amounts were added to eroded soils to make up for the loss that resulted from erosion. As far as slope position which Fran brought up, I expect that analysis would show that the eroded soils might be slightly steeper and slightly more convex. However, the main thing that would be shown is that where we mapped severely eroded soils, these probably would have been farmed a lot harder in the past. I think that would be a consistent difference. They hadn't been protected in the past from erosion, either because the uneroded soils were pasture soils and were not cultivated in the past, or they were otherwise more protected. Soils of the same slope class (e.g., B slope) have approximately the same gradient. The eroded soil may be toward the high end and the uneroded soil toward the low end.

Benbrook wasn't alone in 1980 in thinking that the Yield Soil Loss Simulator had underestimated the productivity loss. Many people felt that was true. If the current EPIC results give even lower estimates of the impact of erosion than Dyke and Hagen, then you start looking for reasons why EPIC gives such low estimates of erosion impacts. There are at least five good, consistent, straightforward reasons, why EPIC underestimates the impact of erosion. Someone should be estimating the extent to which EPIC does underestimate the impact of erosion. I have not heard of good, consistent reasons that EPIC overestimates erosion impact.

The first issue is phosphorous. With eroded soil, the loss of organic matter is associated with soil erosion. Accompanying that loss is a loss of phosphorous. Eroded soils consistently have a very much lower phosphorous level than uneroded soils. The EPIC assumes the phosphorous is replaced as needed to keep productivity up; in fact, farmers are not doing that in their fields. And, my question is, if that is true, then which do you count as the impact of erosion on productivity--the uncompensated loss that actually occurs in the field or the assumption about elevated production due to phosphorous being replaced?

The second issue is EPIC assumes a perfect stand. In my experiences you won't get a perfect stand on a lot of eroded soils.

The third issue is another possible impact would be that the pedon choosen to represent the sloping eroded soil very often was a soil that occurs on less sloping areas. Therefore, it would be less sensitive to erosion damage than the soil that actually occurred on the steeper sloping area where estimates of erosion impacts are needed.

The fourth issue is that the infiltration that would occur on an uneroded soil is also assumed to occur on the eroded soil. It is very likely that you get less infiltration on eroded soil and therefore less available moisture.

The fifth point is that there are little patches just below the eroded slope where sediment from that year covered up the seedlings and you have a loss very difficult to account for. It's off site, I guess, but might not be treated as such.

Without being critical, this may lead us to a point where we can say that if it's possible that EPIC does, in fact, consistently underestimate the impact of erosion on crop yields, someone should analyze how much.

P. Dyke: A sixth reason should be added. The land lost to gully erosion is not included in our analysis of erosion damages.

P. Crosson: If we go on that line, we may not be accounting properly for all kinds of things that go on, including wind erosion. (Although that is included in EPIC, nobody is very happy with it.) The important thing is how accurately does EPIC measure what it purports to

measure, which is essentially loss of productivity because of loss of permanent characteristics of the soil, or characteristics which affect permanent productivity of the soil.

D. Young: Briefly responding to point five, I am aware of some unpublished work by Don McCool, ARS scientist at Washington State University, of erosion effects on plant dislodgement and suffocation. Based on five or six years of data, in one basin in the Palouse, McCool's results showed only 0.3 percent of this basin suffered sedimentation sufficient to suffocate plants. As a consequence, I am not yet convinced that these ephemeral effects are very large.

Also, as point number seven, the ignoring of tillage erosion, wind erosion, and even gully erosion, is another reason, in a gross sense, why EPIC underestimates potential productivity impact.

As reason number eight, again, when you look at the broader process, our lack of understanding of the interaction between erosion and technical progress can also lead to an underestimate.

J. PUTMAN: That could go both ways, it's just that we don't know it.

P. Crosson: On a related issue, I have heard it said, not by economists, that if 1977 or 1982 rates of sheet and rill erosion were to continue for 100 years, that long before the 100 years were up, you would begin to get gullying in those places where this is occurring. And since neither EPIC or PI covers the effects of gully erosion, I would like a response to that. Is gullying, in fact, likely to become a problem in places where now we only have sheet and rill erosion, if sheet and rill erosion continues for a very long time?

J. Williams: I think gully erosion is very important and it probably, in many areas, is the dominant cause of loss of productivity. It is something we have to deal with now, and we have some plans to start doing that.

P. Crosson: In evaluating these estimates that we have of the long-term effects of sheet and rill erosion, which are very small in both PI and EPIC, is it possible that we are somehow missing something important if we assume that on those landscapes that we are looking at, sheet and rill erosion will continue for a 100 years, 50 years, whatever--without gully erosion becoming the important problem. I am not saying gully erosion is now an important problem which is not being picked up, but rather, is gullying likely to become important where now only sheet and rill erosion are important today?

B. Larson: Rather than respond to that, let me make another point. The NRI estimates are really point estimates. They are for a certain slope, a certain slope length, a certain soil. But if you consider that soil in its context with the landscape, you may get somewhat different answers. For example, Onstad, et al. from Minnesota, considered topographic sequences of six soils over a natural landscape. They developed a model assuming Richardson's 100-year rainfall simulation, the CREAMS erosion-deposition model, and the PI model. The six different soil pedons were treated as the natural slope as it occurs in the field. The results indicated an over-all reduction in productivity from an arbitrary initial 1.00 to 0.73 over a 100 years. But if you look at the pedons individually, the PI ranged from 1.22 to 0 as compared to the initial 1.0. Where the limestone came to the surface, PI went to 0. Where deposition occurred, PI increased. Our point is simply that point estimates may give quite a different answer than if you analyze the landscape as it actually occurs in the field. There are some limitations in the NRI data the way we use it.

J. Putman: That's an important point. To go back again to what we said this morning, EPIC measures inherent productivity loss. Any time you have significant erosion rates, the implication is that you have enough runoff to wash a gully somewhere. EPIC estimates are based on points. It removes productivity from those points. Where runoff from points accumulates and creates a gully, acres are removed. This is a different kind of

loss which is not modeled by EPIC. You have to get away from the points and model the geometry of landscapes before you can tie all of this together.

J.Miranowski: It intrigues me that we have put a large group of scientists to work on EPIC over a number of years, and we've erred only on the side of underestimating the impact of soil erosion on productivity. I don't know of very many other cases where we have had a large group of recognized scientists where we have always erred on one side of the issue. Further, the EPIC efforts have been submitted to numerous peers for criticism.

Does EPIC consistently underestimate productivity impacts or is it simply that we have come up with some relatively low productivity impact estimates? And, where might we have erred on the side of overestimation, or is it just a one-sided err? I can think of a few cases from the economic perspective where the error may have gone in the other direction.

T. Robertson: In our review process, as I mentioned earlier, our soil scientists and agronomists were very skeptical in the beginning and very supportive of EPIC at the end of the review process. All through the process they kept saying we were underestimating erosion and yield impacts. They said we were underestimating basically because EPIC estimates the impact on a point. In some cases, the Dyke-Hagen Yield Soil Loss Simulator might be much better, because when they looked at the soil map units, they were getting the impact across the map unit. It was taking into consideration the nobs that are in Orangeville. We had an Orangeville pedon that we ran in EPIC at Temple. When it was reviewed, the soil scientists said that we were not going to get that high a yield on Orangeville. We got a high yield on Orangeville because we had a pedon out of the best part of the field. We didn't have the nob. This is one reason why EPIC underestimates erosion impacts. There may be some overestimations of impact, but I would say, in general, it is underestimating. That was the general feeling of our soil scientists and agronomists throughout the evaluation process. They were concerned about underestimating impacts. But EPIC is not underestimating what it is supposed to be estimating, namely the impact at a point.

K. Renard: Some comments are in order at this point regarding how models evolve and develop. There are stages to model development--in its first stage a modeling effort is revolutionary; and subsequently, it's evolutionary. EPIC went through the revolutionary stage a couple years ago and development now is evolutionary in nature. But one of the problems besetting us as the model evolves is that the conceptualization that takes place with many models such as EPIC is more detailed in its conceptualization, or in its mathematical formulation, than we can develop and design field experiments with which we can make the measurements to validate the model in its entirety. For example, as the model was first postulated and developed, we used some time tested principles, such as curve numbers, USLE, and so forth. We feel comfortable with these knowing something about such technology, but we know there are problems and limitations with them. In many of the other algorithms that are used in a model like EPIC, there have been experiments that have validated algorithms used at a specific site, and often only at a specific site. I'm sure the EPIC authors would say that the nitrogen/phosphorous routines certainly have never been validated over the entire range of problems that we are attempting to simulate with in this modeling process. Furthermore, we are using some technology that was developed in a crash because of time constraints. Now we have to use this technology to do a big job. But we are using technology that at this point is still unvalidated, and will evolve for many years to come. Ultimately this technology will probably be considerably changed from that which we are using today. A further point regarding the model evolution is that the version of EPIC being used in the 1985 RCA is the 12th or 14th or even the 20th version of EPIC and it's only 3 years old. An analogous situation involves SCS with the 9th approximation, 5th revision of the soil classification series or whatever the numbers are. Soil scientists are taking pot-shots at it and I'm sure that

more evolutions of this soil classification scheme will be forthcoming. My end point is that we are talking about things that we really shouldn't be talking about. We don't know whether these model/classification schemes are right or wrong. We don't know whether the productivity reduction of five bushels per acre due to erosion is because we are on the mid-slope point or on the up slope point, or at the toe of the slope. Much of this technology is unknown because the research has never been validated as an entire package. Similarly, the EPIC model needs more validation based on field experiments but even without such validation, the EPIC model, with the known physics upon which it is based, is a sound scientific product.

J. Fletcher: Two points--first, the fertility is not being replaced. I don't have enough experience or knowledge to know that in general, but in at least one study we have done in Indiana where we did a number of sites on farmers' fields and looked at the fertility levels, I would say that is not true. The P and K levels, at least in much of the Corn Belt, are high enough that they are not limiting factors, even on eroded soil. I don't know how generalizable that is, but this was taken in one of the better corn growing areas in Indiana; we can take it for what it's worth.

Second--on slope, we are trying to do exactly that at Purdue. I am working in conjunction with George Foster at the Soil Erosion Lab, and Dave Beasley at Ag Engineering. We are looking at the impact of slope and slope shape and we are trying to combine using EPIC with some of the CREAMS-type models and answers. Another thing in that modeling effort--one of the problems in using EPIC in this particular effort is what do you do in the points of the slope where you get sedimentation and you get soil build-up. As far as we know, and I think it is true, is that it is not handled well in EPIC at this time, so we are making some (probably) horrendous assumptions and they may be somewhat accurate and they may be grossly inaccurate, but we will make them anyway.

Third, a technical point has to do with the way EPIC is being used with the random number generator when you are looking at P-0 and P-1 and the effects of no erosion and erosion on productivity. It is done with a single draw from a stochastic process over a 100-year time horizon and you have to point out that it is a single draw. And yes, it's been looked at as a reasonable weather pattern. But you have no idea what is really going on in the mean of that process, the way it's being used so far. It may be valid--it probably will not be a problem--but until you have looked at what is really going on in a statistical sense, you have to realize that there is a substantial question in that particular area that needs to be discussed.

J. Williams: It is unlikely that accumulated erosion during a 100-year period would vary appreciably for different 100-year weather sequences.

J. Putman: You might want to point out that the weather data sets that we have used have been checked to show no trends. We have eliminated that trend possibility.

J. Williams: I said this morning that EPIC is just a simple hillside model and we are not trying to account for differences in slope configurations or any of that sort of thing at this time. Not that we don't think these things are important, it's just that we tried to do what we could within a reasonable length of time.

C. Ogg: At the time RCA was conducted, there wasn't information about what soils are vulnerable and apparently that is still being developed. If you have a group of soils that you are concerned with, that are vulnerable and make up a small part of the cropland base--and you are not able to have a land group in your sampling that represents those soils--the sample may not represent them. In fact, the sampling procedure would appear to be biased against the vulnerable soils which benefit most from conservation.

K. Flach: There are rarely eroded fields. There are fields where some parts are more eroded than others. The conclusion is that erosion increases soil variability and this soil variability then has a cost factor involved. That means that the farmer has to compensate for the worst parts or there is an environmental effect that the farmer over-fertilizes everything and that is something we will not be able to afford to do in the future. So variability is a big factor, and I think variability then enters into this question. We have sensitive soils in a landscape that are more affected than other soils and that affects the management of the fields a lot more than you would expect just from their geographic importance. We have to deal in fields and not in taxonomic units.

J. Putman: EPIC measures changes in productivity. EPIC output was never intended to measure total benefits and it's not appropriate to talk about EPIC changes in productivity as benefits from conservation. It is not an economic model; no economic evaluation was made. Yes, economic benefit is one thing you have to have, but it's far removed from the concept of total benefits.

B. English: I would like to make two comments. First, the model that is going to be used has been long awaited by production economists, soil scientists, and other people interested in the process of crop growth. It's being used now. We have a version, Purdue has a version, Texas A and M has a version. Different versions of the model is something we will have to grapple with. How do we let people know of model modifications? I am sure that people in the field right now are doing some risk and uncertainty analysis with it; if they are not, it will begin. They will be looking at tillage practices and the infiltration rate; modifications will be made. In the model, by region and area, we have made some modifications for Iowa that we felt were appropriate. We have a research team of agronomists, soil scientists, ag engineers, and economists working together trying to develop a model for 40 basic soils in Iowa. We are very satisfied with it. We are very satisfied with the relative impacts right now. We are trying to get more absoluteness out of the model. The model is going to be used, that's my first point.

The second point is the groundwater issue--pesticide contaminants getting into the groundwater. A great deal of emphasis will be placed on looking at the application of pesticides and chemicals on the crop and trying to track how they filter down to the groundwater. If there is any way that EPIC can give us some insights in this particular area, I would encourage an effort of some sort be made at a national level.

B. Caldwell: The previous commentor makes a good point when he says the model will be used. In fact, the data is already being used--the model is in place! Earlier, someone commented that further development of EPIC might be part of the research agenda for the future. Many of us believe such an effort is important. I am really pleased to think that we are moving along with EPIC and that people are seeing additional things that need to be done.

The problem as I see it comes in terms of the fact that the EPIC outputs <u>will</u> be used. EPIC is no longer a theoretical model. There are research scientists here that will use it--soil scientists, myself, and others. For example, I want to use the meteorological and growth model portions of EPIC to help farmers evaluate risk and uncertainity. There are program developers and managers who will be using it to design and operate programs. Even more importantly, there is a gentleman from OMB attending this session who will be using EPIC results to evaluate the effectiveness of those programs in meeting actual resource needs. Therefore, if we have some omissions in EPIC, and I don't want to even think about errors, we need to know about those omissions very specifically. I would charge the folks who are responsible for these models to specifically identify what the models do cover and, to the extent that they can, what the models don't cover. This evaluation should occur as soon as possible. This is extremely important if we are trying to evaluate the national extent and importance of the erosion problem. We may be in for serious trouble if we provide EPIC-derived informa-